Peer Review of the National Highway Traffic Safety Administration Program

Workshop Proceedings

Sponsored by
ITS America Advanced Vehicle Control Systems Committee, Safety and Human Factors Committee, and the National Highway Traffic Safety Administration

Baltimore, Maryland
December 11-12, 1995

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ITS America

ITS America is a non-profit educational and scientific association incorporated in August 1990 to plan, promote, and coordinate the development and deployment of intelligent transportation systems in the United States. The association is designed as a utilized Federal Advisory Committee to the US Department of Transportation (US DOT). Members of ITS America include the transportation, communications, and electronics industries; government agencies at the local, state, and federal levels; academic institutions and related associations. The Society is open to international membership, both public and private.

Abstract

The National Highway Traffic Safety Administration prepared an Intelligent Transportation Systems Program Plan as part of the early planning for the Intelligent Transportation System (ITS) work within the Department of Transportation. Commercialization of effective collision avoidance systems, is one of the ultimate goals of the ITS program plan. To help achieve this goal, NHTSA established contracts to develop safety-based performance specification/guidelines for systems that would address four high-priority types of collision: Rear-end collisions, collisions at intersections, single vehicle road departure collisions, and collisions associated with vehicles, pedestrians, or other objects in the driver's blindspot.

The status of these projects was presented at a "peer review" workshop jointly sponsored by NHTSA and the Intelligent Transportation Society of America. This was the third in a series of jointly sponsored workshops which have focused on the NHTSA collision avoidance activities and the safety benefits associated with collision avoidance systems. The workshop provided participants opportunities to review and comment on the NHTSA collision avoidance research program, as well as provide in-depth discussions of the first three programs via participation in breakout groups. Four specific questions posed to workshop attendees included: (a) Are the performance specifications on the "right track?" If not, what are the suggestions for a different approach?; (b) What experiences or lessons learned can be offered for incorporation into the NHTSA program?; (c) Will the eventual results from the NHTSA work be useful to system designers? If not, what would be useful?; and (d) What guidance can be provided on methodologies to estimate the benefits which would accrue to systems designed to meet the performance specifications? These proceedings summarize the workshop findings.

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A Workshop on Peer Review of the National Highway Traffic Safety Administration Program

December 11-12, 1995

Baltimore, Maryland

NHTSA's Collision Avoidance Research Program

The National Highway Traffic Safety Administration (NHTSA) has initiated a research program to facilitate development and early deployment of cost-effective, user-friendly collision avoidance systems. Two key goals of this program include: the development of performance specifications for crash avoidance products and systems, and the development of a vital set of research tools which contribute to our understanding of the safety benefits and potential liabilities associated with new products. In order to achieve these goals, the agency is establishing technology independent functional requirements for various collision avoidance safety systems, and sponsoring research designed to develop innovative research tools and analytic techniques necessary to evaluate crash avoidance concepts and to establish a more comprehensive knowledge base of driver-vehicle performance and behavior.

The Workshop

This workshop provided an opportunity for the exchange of information on the state-of-development of collision avoidance system performance specifications. It also provided an opportunity for an exchange of views on the development and utilization of two new collision avoidance research tools. Participants were briefed by the researchers who are carrying out the programs and were provided opportunities to review and comment on the National Highway Traffic Safety Administration collision avoidance research program. Presentations addressed the current status of projects as well as extensive research which forms the basis for preliminary performance guidelines. Breakout sessions provided an opportunity for sharing information and suggestions with other professionals in the field, in addition to the researchers and NHTSA staff. This was the third in a series of jointly sponsored workshops which have focused on the NHTSA collision avoidance activities and the safety benefits associated with such systems.

The Agenda

This two-day workshop primarily consisted of project presentations and breakout group sessions as presented in Table 1.

Project Presentations/Invited Papers. The status of various NHTSA projects, outlined in Table 2, were presented. Project leaders discussed in detail the work that has led to preliminary performance specifications for systems that address each of three types of collisions: rear-end collisions, lane change, merge, and backing collisions, and roadway departure collisions. During the remaining phases of each of these contracts, research testbeds will be constructed and extensive testing will be performed in order to refine the preliminary performance specifications. The testing will emphasize performance features of the functional elements of each system; including sensors, threat detection algorithms, and driver/vehicle interfaces. Project briefings associated with the development of two research tools, designed to facilitate analysis of test and system assessment data were also provided.

Breakout Group Sessions. Workshop participants were separated into three breakout groups, each of which discussed the following:

- Rear-end collision avoidance using ITS countermeasures.
- Lane change and merge collision avoidance using ITS countermeasures.
- Run-off-road collision avoidance using ITS countermeasures.
- Applications of DASCAR and VME collision avoidance research tools.

The breakout groups were asked to respond to the following four questions in the context of each of the three collision avoidance system specifications:

(a) Are the performance specifications on the “right track?” If not, what are the suggestions for a different approach?
(b) What experiences or lessons learned can be offered for incorporation into the NHTSA program?,
(c) Will the eventual results from the NHTSA work be useful to system designers? If not, what would be useful?, and
(d) What guidance can be provided on methodologies to estimate the benefits which would accrue to systems designed to meet the performance specifications?

Table 1. Workshop Agenda

Mondav. December 11

Introduction - Steve Shladover

7:45 - 830 Registration
8:30 - 9:00 Welcome/Opening Comments - Ricardo Martinez, M.D.
9:00 - 9:30 Meeting Objectives - August Burgett

Project Presentations/Invited Papers

9:30 - 10: 15 IVHS Countermeasures for Rear-End Collisions
10:00 - 10:30 Break
10:30 - 11: 15 Collision Avoidance System Performance Specifications for Lane Change, Merging and Backing: Phase I Results and Future Plans
11: 15 - 12:00 Program Overview: Run-Off-Road Collision Avoidance Using IVHS Countermeasures
12:00 - 1:15 Lunch
1: 15 - 1:30 Introduction to NHTSA "Tools"
1:30 - 2:10 Data Acquisition System for Crash Avoidance Research
2:10 - 2:50 Status of a Measurement and Processing System for Characterizing the Vehicle Motion Environment (VME)

Breakout Groups Sessions

2:50 - 3:00 Breakout Group Instructions
3:00 - 3:30 Break
3:30 - 5:00 Breakout Groups

Tuesdav. December 12

8:30 - 12:OO Breakout Groups
12:00 - 1:15 Working Lunch
1: 15 - 2:45 Breakout Group Reports - Gene Farber (Moderator)
2:45 - 3:00 Break

Summary and Closing Comments

3:00 - 3:45 Rapporteur's Perspective - Robert Ervin
3:45 - 4:00 Closing Comments - August Burgett, Steve Shladover, and Gene Farber

Table 2. NHTSA Projects: Performance Specification and Research Tools.

Collision Avoidance Systems: Performance Specification Projects	
Countermeasures Against Rear-End Collisions	This project will lead to the development of performance requirements (both hardware and human factors) for advanced technologies to prevent or decrease the severity of rear-end crashes. Contractor: Frontier Engineering, Inc. Completion Date: January, 1998
Countermeasures Against Lane Change, Merge, and **Backing Collisions**	This project will lead to the development of performance requirements (both hardware and human factors) for advanced technologies to improve crash avoidance during lane change, merging, and backing maneuvers. Contractor: TRW Completion Date: July, 1997
Countermeasures Against Roadway Departure (Run-Off-Road) Collisions	This project will lead to the development of performance requirements (both hardware and human factors) for advanced technologies to improve crash avoidance during roadway departures (run-off-road). Contractor: Carnegie Mellon University Completion Date: September, 1998
Collision Avoidance System: Research Tool Projects	
Data Acquisition System for **Crash Avoidance** Research (DASCAR)	The objectives of this project are to apply state-of-the-art technology and methods to develop an easily-installed, portable instrumentation package and a set of analytic methods/tools to allow driver-vehicle performance data to be collected using a variety of vehicle types. Contractor: Oak Ridge National Laboratory Completion Date: December, 1995 (Phase I)
System for Assessing the Vehicle Motion Environment (SAVME)	**This** project will develop and validate a measurement system that can quantify the specific motions that vehicles exhibit as they move in traffic under the full array of traffic operations. In subsequent projects, the measurement system will be used to gather information such as reactions to other drivers cutting in front, normal following distance and typical lane change trajectories. This information will provide the foundation for development of ITS countermeasures that identify the need for intervention and/or collision avoidance instructions to the driver. Contractor: University of Michigan Transportation Research Institute and the Environmental Research Institute of Michigan Completion Date: August, 1996

Acknowledgements

The workshop and these proceedings were jointly sponsored by ITS America and the United States Department of Transportation National Highway Traffic Safety Administration (NHTSA). ITS America and the NHTSA would like to express their appreciation to the meeting attendees, and to the support contractors for sharing this important work with us. We would like to thank Steve Young from TRW, Terry Wilson from Frontier Engineering, Dean Pomerleau from Carnegie Mellon University, Bob Ervin from the University of Michigan Transportation Research Institute, Kent Gilbert from the Environmental Research Institute of Michigan, and, Dick Carter and Frank Barickman from Oak Ridge National Laboratory for their presentations.

We would also like to thank the co-chairs of this meeting; Steve Shladover as Chairman of the Advanced Vehicle Control Systems Committee of ITS America and Eugene Farber as Chairman of the Safety and Human Factors Committee of ITS America. These two gentlemen have served us very well in this forum as in previous forums. We would also like to acknowledge Mike Martin, Mark Freedman and Steve Shladover who managed these breakout sessions, and the workshop organizing committee consisting of August Burgett, Eugene Farber, Mark Freedman, Michael Martin, Donna Nelson, and Steve Shladover. Finally, we want to acknowledge the NHTSA staff, and staff from other U.S.DOT offices for serving as session recorders.

Section I: Introduction

Speech to the ITS America/NHTSA Peer Review Workshop

Dr. Martinez
Administrator
National Highway Traffic Safety Administration

Good morning. Welcome to this workshop where you will discuss one of NHTSA's important initiatives to improve injury prevention on our highways. We believe that our ITS collision avoidance program represents the preventive medicine of our highway collision disease and are very pleased to see so many people here today to discuss this program. At the outset, it should be noted that our complete ITS program involves more than just support for the development of collision avoidance systems, which are of course the topic of this workshop. Another area is the improvement of emergency medical service in this country. We recently initiated an operational test of a system for automatic notification of emergency personnel of the occurrence, location, severity of crashes so that appropriate emergency care can be dispatched. We are also involved with other partners in the evaluation of the safety impact of other ITS technologies. For example, we worked with the FHWA, GM, AAA, the state of Florida, and the city of Orlando to evaluate the impact on safety of the TravTek route guidance and navigation system.

As background to our interest in the safety potential of ITS, let me briefly review the road NHTSA has taken to improve highway safety. During the early years of NHTSA, the agency emphasized regulations in the area of crash avoidance-- preventing a crash from occurring and crashworthiness-- reducing the level of injury, given that a crash has occurred. Crash avoidance regulations issued by the agency include antilock brakes on heavy vehicles and performance requirements for vehicle systems, such as lighting, visibility, and brakes. The agency has also issued many significant crashworthiness regulations over the last 20 years. Among the more noteworthy are standards for frontal and side crash protection of occupants, interior head impact protection, fuel system integrity, and the recent requirement for air bags. Analysis of accident data indicate that our safety standards have saved over 112,00 lives and prevented many injuries. Despite this impressive progress, much remains to be done. While further improvements in crashworthiness are possible-- such as improved frontal crash protection, stronger doors, and glazing to prevent ejection and others, a great opportunity exists to reduce casualties by focusing efforts on crash avoidance (i.e., to reduce the risk of crash occurrence). This is the opportunity and challenge that is the driving force behind the NHTSA ITS program and the subject of this workshop.

Our analyses of real-world accident data concluded that about 90% of crashes result from driver-related factors, including drivers not recognizing a hazardous situation until it is too late to do anything about it (inattention, looked but did not see), drivers making the wrong decision (tailgating, excessive speed), and drivers in a poor physiological state (drunk, asleep, ill). If all of these driver problems could be totally eliminated, the potential exists for reducing the number of police-reported crashes each year from six million to 600,00. While we don't have definitive estimates of how effective they will be when they are implemented, it is clear that if ITS collision avoidance systems could provide even half of potential, they would represent a tremendous reduction in the heavy toll of motor vehicle collisions, including the massive economic consequences.

NHTSA has been involved in the DOT ITS program from its inception and provides leadership on safety systems and issues within the program. Early-on in the program, we recognized the need for an organized approach to the development of meaningful guidelines for intelligent collision avoidance systems. This workshop is our first opportunity to share the results of this work with our partners and stakeholders. The program for development of collision avoidance systems contains four parts. We believe that this multifaceted four-part approach will provide the U.S. taxpayers with the best return on their investment and provides NHTSA with the ability to develop and implement ITS technologies in an orderly and scientific manner so as to achieve a large part of the potential safety benefits.

The first part is a comprehensive crash data assessment to develop an understanding of the safety problem. This assessment allows us to define potential countermeasures which could prevent crashes. We have completed a through analysis of our accident files, including detailed analysis of individual cases. The results of this analysis have quantified the real-world crash problem and the causal factors of various crash types. For example, we found that in rearend collisions, 85% involve driving task errors. In single vehicle roadway departures, 49% involve such drivers errors, while 25% are attributed to the vehicle or the road surface. These two types of casual factors--driver errors and the roadway--demand different solutions to avoid crashes. In the first case, information about the proximity of other vehicles in the lane needs to be conveyed to a driver in manner that demands immediate corrective action. In second case, information about the vehicle's location to the roadway and relative velocity to the roadway edge must be provided to the driver. Also, in the case of roadway-caused events, information about road and other hazardous conditions needs to be conveyed to the driver sufficiently in advance so that the driver can slow down or take other remedial action. These different approaches will be discussed in more detail by some of the following speakers.

The second part of the program is directed at converting our understanding of the target crash populations into systems in vehicles and the driving environment that can help avoid collisions. Here, we establish the performance specifications that specify the technical attributes for systems which can address a safety problem defined in the first part of the program. We currently have projects that are developing performance specifications for Rearend Collision Avoidance, Lane Change and Merge Collision Avoidance, Run-Off-Road Collision Avoidance, Backing Collision Avoidance, Intersection Collision Avoidance, Drowsy Driver Collision Avoidance, and Reduced Vision Collision Avoidance. Today, we will be discussing the first four of these. The others are more long term and may be the subject of future workshops. This part of the program also develops countermeasure concepts that would satisfy the performance specifications. For example, the problem of an unexpectedly slow moving vehicle in front of a driver could be addressed by an intelligent cruise control system that warns the driver of insufficient headway, whereas the problem of the stopped vehicle would need to be addressed by a more aggressive collision avoidance system that either advises the driver of the need immediate action or automatically assists in stopping the vehicle.

The third component of our program is to take these countermeasures and demonstrate that they are production-feasible and can be efficiently introduced into production vehicles. This is typically done by an operational test in which a system is introduced into a sample of vehicles to be used by the public. After the field test is completed, all the information gathered is evaluated. The results of this analysis provides insight into the expected real-world effectiveness of the system, indicates potential consumer demand, and defines all the components necessary to fully implement the system.

The fourth, and perhaps most critical, component is the assessment of benefits that are provided to the driving public by ITS collision avoidance systems. Estimates of the number of collisions that will be avoided and the resulting reductions in property damage costs, deaths, and injuries are needed to provide guidance on program direction and, of equal importance, to be able to share with the U.S. taxpayers, evidence that their money is being well spent. To the best of our knowledge, no one has yet attempted to quantify ITS safety benefits using a scientific approach of which will result in estimates of potential safety benefits. Critical to our approach of assessing safety benefits is the development of test tools to help us better understand and quantify a safety problem and to estimate the effectiveness of ITS countermeasures. Before continuing the discussion of safety benefits, I would like to briefly describe these tools. Two of the four research tools which are being developed by NHTSA will be discussed at this workshop. One is DASCAR which stands for Data Acquisition System for Crash Avoidance Research. It is a set of instruments and supporting computers and communication equipment that will travel with a vehicle and monitor a driver's actions and the vehicle's response. DASCAR will provide insights into the actions drivers take in the driving environment , including how drivers survey the driving environment, and what action drivers take to avoid collisions in their everyday driving experience. The second tool is the System for Assessing the Vehicle Motion Environment (SAVME). This is a tower-mounted observation platform that can view traffic activities and record the relative motions and actions of each vehicle as it travels through the field of view. The motions of each vehicle are recorded and processed to provide information on the relative proximity and motion of vehicles to assist in relating these parameters to crash risk.

Two other tools which we are developing won't be discussed at this workshop. They too, are longer term and may be the subject of future workshops. One of them is the VDTV which stand for Variable Dynamics Testbed Vehicle. It will be a test-track vehicle that can present the driver with a wide range of vehicle characteristics and control mechanisms. It will be used to assist in defining the boundaries of control actions that are essential for safe operation of vehicles. These Boundaries will also play a key role in determining the precise timing for advising the driver in advance of impending crash. If information is presented too early , it will be considered to be a nuisance by many drivers and the effectiveness will be diminished. If, on the other hand, advice is given too late for the driver to effectively take action, the system would be ineffective. Our fourth tool is NADS, which stands for the National Advanced Driving Simulator. It will be a state-of-art driving simulator that will allow drivers to be safely exposed to a full range of driving conditions, including those that simulate vehicle operations that pose major safety risks. The simulator would provide the ability to perform detailed experiments in which drivers could be exposed to driving situations with and without ITS technologies. The simulator will also be used to determine scientific-based estimates of effectiveness of safety countermeasures. We anticipate the simulator to be fully operational by December 1998. As the world's most advanced simulator, we strongly encourage other users to take advantage of this tool in researching various human factors issues.

Let me now return to benefits assessment. We recognize that the most accurate estimates of system benefits can be obtained only after systems are available and in widespread use. However, we also believe that it is possible to make preliminary estimates based on results from a variety of research projects, especially those based on laboratory studies involving the tools described earlier.

The initiative to develop a process for estimating benefits was begun earlier this year at the Safety Evaluation Workshop, in May, 1995, which was also jointly sponsored by NHTSA and ITS America. As we worked on the development of performance guidelines for collision avoidance systems, it became clear that we must initiate efforts to translate these performance specifications into potential safety benefits. This is critical in order to provide the information necessary to make informed decisions concerning the benefits and costs of various ITS strategies.

Last month, at the ITS World Congress in Yokohama, Japan, the Deputy Administrator of NHTSA, Phil Recht, announced that we are continuing our effort to develop credible estimates of benefits through an internal task force. The work of this task force will focus on developing a methodology for benefits assessment by comparing the estimated number of collisions when driving <u>without</u> an ITS collision avoidance system to the number expected when driving with a collision avoidance system. Our preliminary benefit assessment will be based on data from driving simulators, computer models, test track experiments, and expert opinions. We anticipate that, in the near term, both DASCAR and SAVME will provide baseline information which will be used for early estimates of benefits. The initial estimates of benefits will provide NHTSA with the basis for making decisions about various ITS approaches. We plan to present the preliminary results of our efforts at the ITS America Annual meeting in Houston in April.

We believe that this benefit assessment will represent a unique effort to establish credible estimates of benefits for collision avoidance concepts at an early stage of development. These estimates should not only help NHTSA make decisions about the direction of the ITS Crash Avoidance Program, but should also help the entire ITS community to make decisions on the most cost-effective allocation of resources. We look forward to the results of the discussion at this workshop as we continue to evolve NHTSA's role in the development and deployment of effective collision avoidance systems. Our efforts include encouragement of certain industry actions, regulations, consumer information, and additional research-- all towards improving automotive safety.

Thank you for the opportunity to share some details of our ITS collision avoidance program. We are excited about the potential savings in lives, injuries, and other costs that may result from this application of advanced technology. We believe the results of this workshop will be of great help in guiding our ITS collision avoidance program.

Presentation to the Opening Session of the NHTSA/ ITS America Peer Review Workshop

A ugust Burgett
December I I, 1995

INTRODUCTION

I recently had the opportunity to take some training in limit condition driving. One of the exercises involved trying to steer on a very slippery surface. During the first attempt, I lost control of the car and it spun around two or three times, finally coming to rest facing in the opposite direction that I was going. The instructor then said there are two critical elements to successfully performing this type of driving: (1) pick a target on the horizon and keep your eye on it, and (2) steer with great vigor. When I followed these instructions I was able to successfully maneuver on the slippery surface. I believe the same advice applies to our ITS program; i.e. pick a long range goal and keep our eye on it, and provide continuous interaction and steering of the projects. The goal we have selected for the collision avoidance program is the availability to American taxpayers of effective collision avoidance systems as early as possible. We believe that we have the right projects in place for meeting this goal and that we are working with our partners on a day-to-day basis to achieve this long range goal. During this workshop we would appreciate any feedback on whether we have the right long range goal and whether our day-to-day leadership is moving toward accomplishing this goal.

ORGANIZATION

About five years ago when we started planning collision avoidance program, it became obvious that we needed to take steps to get a better understanding of the details of the collision avoidance problem. We asked our colleagues at Volpe National Transportation Systems Center to help us by doing a thorough review of collision data from our Crashworthiness Data System and from the General Estimate System. In very brief summary, the work showed us the basic mix of collisions that occur [see Figure 1] and that driver factors are the primary causal factors in collisions [see Figures 2 and 3]. This initial work was followed by several projects that each focused on a specific type of collision [see Figure 4]. These initial projects addressed rearend collisions, road-departure collisions, lane change/merge collisions, backing collisions, and intersection collisions. Subsequently we started projects to look at drowsy driver collisions and collisions where enhanced vision of the road ahead would be helpful. In each of these projects, we are following the same sequence of tasks. We believe that these tasks will lead to a methodical development of improved understanding of the necessary and sufficient features of collision avoidance systems [see Figure 5]. We asked each contractor to pursue their projects independently from the other projects so that we could get several perspectives on how to go about meeting the challenge of developing performance guidelines for systems which did not readily exist.

DISTRIBUTION OF CRASH TYPES

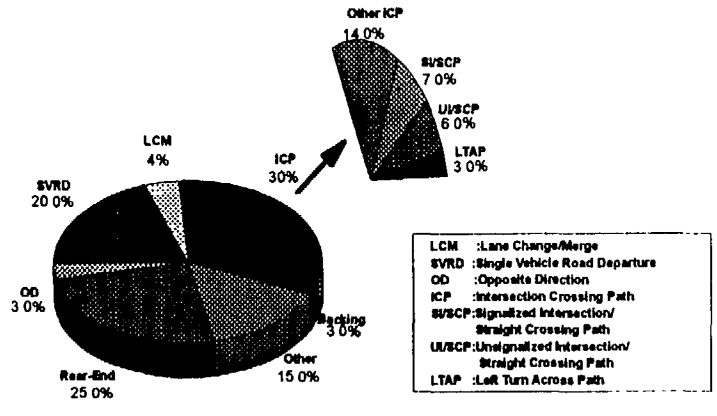

Figure 1

Causal Factors Breakdown

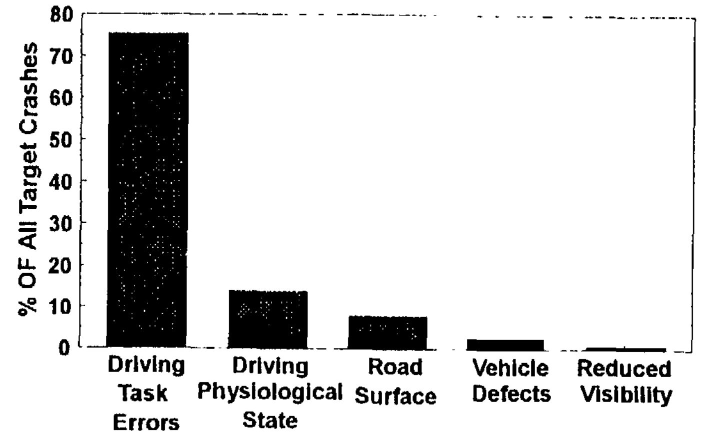

Figure 2

Breakdown of Driving Task Errors

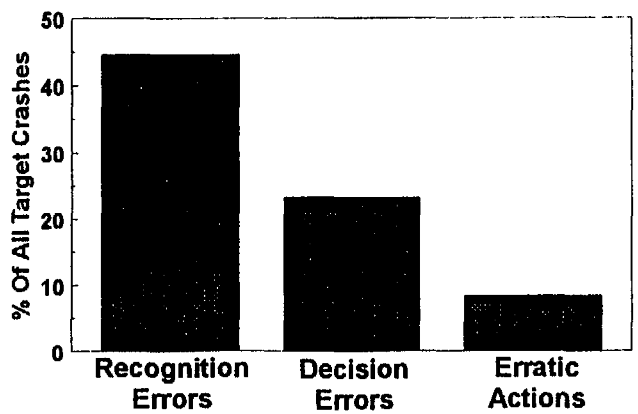

Figure 3

PERFORMANCE SPECIFICATIONS

- Countermeasures Against Rear-End Collisions
- State of the Art Research And Technology Review for Driver Vision Enhancement Systems
- Countermeasures Against Lane Change, Merging and Backing Collisions
- Countermeasures Against Roadway Departure Collisions
- Countermeasures Against Intersection Collisions
- Driver Status/Performance Monitoring

Figure 4

We're happy to be able to share with you today the results of the Phase I work from three of these projects. Time constraints of this workshop prevented us from presenting results from all of the projects. You will be hearing from the leaders of each of these projects during the next two days so I will leave the details to them. As a roadmap that might be useful in seeing the common ground between projects, I asked Kevin Dopart at Mitre to compare the organization of each of the preliminary performance specifications and place them in a common format [see figure 6]. More details of this comparison are in an appendix to the written version of these remarks.

If we look ahead to the work that will follow this preliminary step it includes the completion of the performance guidelines in this current round projects. Coupled with this will be an effort to develop and apply methodologies for estimating benefits of these advanced collision avoidance systems. In the longer term , we will be extending the performance guidelines from these projects to include objective test procedures to assess system performance. These objective test procedures could be the basis for standardization work or other efforts where specific objective test conditions are needed. We will also be working with various partners to develop operational tests which can demonstrate the availability of practicable solutions and systems. [see Figure 73. We welcome any thoughts you have during the workshop on these projects or on future activities.

BENEFITS

Let me turn for a few minutes to the question of benefits. The bottom line of our work is the availability of systems that can help prevent collisions, and the resulting injuries and deaths. Designs which satisfy a set of performance guidelines will not be identical and every element of system design will have a bearing on the effectiveness of the system in helping drivers avoid collisions. For example, one system might issue a warning every time there is the potential for a collision even though one is not imminent. Another system might only issue a warning at the latest time possible before an imminent collision. Another example of system variation, is type of driver interface that is provided. One system might emit a momentary tone or visual image at the first instance that a threat is perceived and then immediately return to a quiescent state. Another system might produce a continuous warning until the threat has passed. These system variations, even if the system performs perfectly to the system design, have consequences on effectiveness of eliciting the correct driver response in a timely manner and on the overall acceptability of the system. One of our challenges is to develop and apply methodologies which can provide estimates of the number of prevented collisions. The methodologies will probably vary with the stage of development of concept or system. For example, a methodology for application to data from an operational test might be based on the number of near-misses whereas a methodology for an earlier stage of development might rely on analytical tools and estimates of the number of collisions with and without a system. Although methodologies for estimating benefits is not a specific topic during this workshop, as it was at the workshop held in May of this year, we welcome any thoughts that you have on methodologies or applications.

PROGRAM OUTLINE

- Phase I: LAYING THE FOUNDATION
  - Task 1: Crash Problem Analysis
  - Task 2: Establish Functional Goals
  - Task 3: Hardware Testing of Existing Systems *
  - Task 4: Develop Preliminary Performance Specification
- PHASE II: UNDERSTANDING THE STATE-OF-THE-ART
  - Task 5: State-of-the-Art Review
  - Task 6: Design
- PHASE III: TEST AND REPORT
  - Task 7: Building
  - Task 8: Testing
  - Task 9: Final Report

* Not included in intersection project due to lack of available systems for testing

Figure 5

Organization of Functional Characteristics

- Monitor and Assess Key Operational Parameters
  - Monitor own vehicle system state
  - Monitor other vehicle / target state
  - Monitor infrastructure configuration
  - Monitor operating environment
- Process CA Data / Information
  - Track "threats"
  - Predict "events"
  - Compute resolution advisory / instructions
- Interact with Vehicle/Driver System
  - General status
  - Provide warnings
  - Provide advisories / instructions
  - Maintain or regain safe condition
- "Interact" with other Vehicle or Infrastructure
  - Coordinate with infrastructure
  - Coordinate with other vehicles

Figure 6

Next Steps

- Completion of the Performance Guidelines
- Development and Application of Methodologies for Estimating Benefits
- Extension of Performance Guidelines to include Objective Test Procedures
- Demonstration of the Availability of Practicable Solutions and Systems

Figure 7

NHTSA ITS "Tools"

- DASCAR
  (Data Acquisition System for Crash Avoidance System)
- SAVME
  (System for Assessment of Vehicle Motion Environment)
- VDTV
  (Variable Dynamics Test Vehicle)
- NADS
  (National Advanced Driving Simulator)

Figure 8

RESEARCH TOOLS

Early in the program, we came to the conclusion that additional research tools were necessary to enable us to develop an adequate understanding of the impact of intelligent collision avoidance systems on driver performance. This has led us to develop four tools, two of which will be discussed at this workshop [see Figure 81. We chose to discuss the System for Assessment of the Vehicle Motion Environment (SAVME) and the Data Acquisition System for Crash Avoidance Research (DASCAR) at this workshop because they should be ready for use before the other two, and also because we think will play an important role in our estimation of benefits. Both of these data acquisition systems will allow us to observe how drivers perform the normal driving functions; DASCAR from within the vehicle and SAVME from outside the vehicle. Just to give a couple of examples, consider the question of where to mount a visual display for a system which would help avoid lane change collisions. An important piece of information is the sequence of steps the driver goes through before starting to change lanes: For example, does the driver look in the center rearview mirror before looking through side glass or vice versa? Experiments with DASCAR will help us answer these kinds of questions. Similarly, it would be good to know the value of time-to-collision when drivers brake under conditions such as a string of vehicles at a stop sign. This information, which can be obtained by SAVME, would help in setting the criteria for issuing a warning. Finally, these two systems will be helpful in developing better understanding of near-misses which will help us develop better benefits-estimation methodologies. Any advice that you can provide on experiments or other uses of these tools will be helpful as we move forward to the use of these tools.

Once again, I would reiterate Dr. Martinez' words of welcome and would encourage each of you to scrutinize our work and provide feedback to help us improve it.

Section II: Invited Papers

Section II consists of a series of invited papers, listed below, which were presented at the workshop.

INVITED PAPERS

IVHS Countermeasures for Rear-End Collisions
Terry Wilson

Collision Avoidance System Performance Specification for Lane Change, Merging and Backing: Phase I Results and Future Plans
Stephen Young

Program Overview: Run-Off-Road Collision Avoidance Using IVHS Countermeasures
Dean Pomerleau

Data Acquisition System for Crash Avoidance Research
Richard Carter and Frank Barickman

Status of a Measurement and Processing System for Characterizing the Vehicle Motion Envimnment (VME)
Robert Ervin, Charles MacAdam, and Kent Gilbert

IVHS Countermeasures for Rear-End Collisions

Terry Wilson
Frontier Engineering, Inc.

INTRODUCTION

IVHS Countermeasures for Rear-End Collisions is a four year (program inception May 1993) multi-phase program sponsored by the National Highway Traffic Safety Administration (NHTSA), Office of Crash Avoidance Research, and performed by Frontier Engineering Inc. The primary objective is to develop practical performance specifications for forward looking (rear-end) vehicular collision avoidance systems.

To develop the performance specifications, the following steps will be taken:

PHASE I, Initial Work (complete)

- Analyze the rear-end crash problem to determine the nature of and quantify the causes of rear-end collisions, and identify opportunities to intervene in the accident process.
- Establish a set of functional goals, or opportunities for intervention, for countermeasures systems.
- Perform hardware testing of existing systems.
- Develop preliminary performance specifications based on the testing of existing systems, modeling and simulation efforts, and evaluation of test data.

PHASE II, Understanding the State of the Art (in-process)

- Review all relevant technologies for sensing, processing and interacting with the driver and select those with the greatest applicability.
- Develop a countermeasures test bed system(s) that addresses key issues in the preliminary performance specifications.

PHASE III, Test and Report

- Construct the test bed system, and conduct testing to support development and verification of performance specifications
- Publish performance specifications that are technology independent and that are based on the analysis and test results.

OVERVIEW

The specifications developed under this program, establish the performance and test[1] requirements for a rear-end collision avoidance system for improving highway safety. Rear-end crash warning and control is a sub-service of the longitudinal collision avoidance user service as defined in the National Program Plan for Intelligent Transportation Systems[2]. The goal of this user service is a reduction in the number and severity of longitudinal collisions. A longitudinal collision is defined as a two-vehicle collision in which vehicles are moving in essentially parallel paths prior to the collision or one in which the struck vehicle is stationary.

According to data from the General Estimates System (GES) and Fatal Accident Reporting System (FARS) databases, rear-end collisions are the second largest single category of collisions. They represented about 23% of all collisions. Studies have shown that in upwards of 90% of rear-end collisions driver inattention/distraction and/or following too closely were contributing factors[3]. This information leads to the conclusion that a rear-end collision avoidance system might be beneficial in reducing the total number of vehicular accidents and that a system that aids the driver's capabilities, by giving a warning of an impending collision situation or maintaining a headway for example, could provide this service.

Systems that provide this service will assist the driver by: (1) sensing potential and/or impending collisions or dangers to the front of the vehicle; (2) eliciting proper collision avoidance actions from the driver; and/or (3) providing temporary automatic control of the vehicle to assist in avoiding the potential collision situation. Collision avoidance systems will typically contain subsystems performing three separate functions: perception, processing and presentation. These subsystems are for sensing critical information about an impending collision, processing the information into a form which is usable by the driver or an automatic controller, and presenting this information to the driver (or directly to the vehicle) in a manner which elicits appropriate collision avoidance action. In systems where automatic action is taken by a controller, it is necessary to ensure that the actions are compatible with vehicle and driver capabilities and limitations. It is also important that the system be self-diagnosing in order to limit the negative impact of system failures.

The specification to be presented at the Peer Review Workshop establishes the performance and test requirements for a particular class of rear-end collision avoidance system, a Driver Warning System (DWS). Driver Warning Systems would help avoid collisions through driver notification. A driver response or action would be elicited upon detection of a dangerous situation or an impending collision. The driver maintains full control of the vehicle.

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1. The test requirements for rear-end collision avoidance devices will be developed and incorporated during the remainder of this contract. Availability of this information will be in the 1996 time frame.

2. National ITS Program Plan, First Edition, March 1995, Volume II, Section 7.1, page 271

3 .Based on data from studying the 1991 NASS GES and CDS as well as the 1992 NASS GES and CDS with the new pre-crash variables.

APPLICABLE DOCUMENTS[4]

Motor Vehicle Crash Involvements: A Multi-Dimensional Problem Size Assessment, USDOT / NHTSA, Office of Crash Avoidance Research, October 1995.

Rear-End Crashes: Problem' Size Assessment and Statistical Description, USDOT / NHTSA, Office of Crash Avoidance Research, May 1993.

Preliminary Human Factors Guidelines for Crash Avoidance Warning Devices, COMSIS and CTA Inc., NHTSA Project No. DTNH22-91-C-07004, October 1993.

New Rules to Increase the Amount of Spectrum Available for Commercial Use, Federal Communications Commission, ET DOCKET 94-124, Adopted: October 20, 1994.

Performance Standard for Laser Radiation Emitting Products, Part 1040, 21 CFR, Department of Health and Human Services, Food and Drug Administration.

REQUIREMENTS

A Driver Warning System (DWS) monitors the forward path of the host vehicle and provides warnings to the driver if the headway presents a potentially dangerous situation[5]. The warning / suggestion can be either imminent or cautionary (or both) through a visual display which can be accompanied by supplemental auditory or haptic[6] (tactile) indications.

Rear-end collisions occur under various dynamic situations, and the system must meet the requirements of this specification under all kinematics of the host and target vehicle. When the warning/suggestion is issued, the target vehicle may be stopped, traveling at a constant speed, accelerating, decelerating, or decelerating to a stop. The host vehicle may be moving at a constant speed, accelerating or decelerating.

The system shall detect all licensable vehicles and evaluate performance relative to this specification. The following types of vehicular targets are included: cars, light trucks, buses, heavy trucks, towed trailers, and motorcycles. These vehicle types shall be detected and tracked without the requirement for special vehicle reflectors or an unreasonably high minimum cross sectional area. Additionally, the system may detect other objects in the forward path.

Some parameters in this specification are a function of the overall system effectiveness. Many times, a tradeoff may be required between effectiveness and cost or technical feasibility. A 97% effectiveness appears to be technically feasible for items that makeup the overall system effectiveness. This would make system errors insignificant compared to environmental factors, such as road conditions, or driver characteristics, such as driver response to the system,, It is recommended that an effectiveness of 97% be used as a goal, for each of the individual

4. Two other specifications exist as part of this contract. One covering Automatic Control Systems and one covering Adaptive Cruise Control Systems.
5. This can also include cooperative systems as long as the driver is adequately warned of impending collisions.
6. Haptic includes tactile (touch) and proprioceptive (pressure) sensory feedback.

specifications herein. The product of the individual specifications are used to determine overall system effectiveness.

DIAGRAMS

A block diagram of a Driver Warning, rear-end collision avoidance, system is shown in Figure 1 including external influences and interfaces.

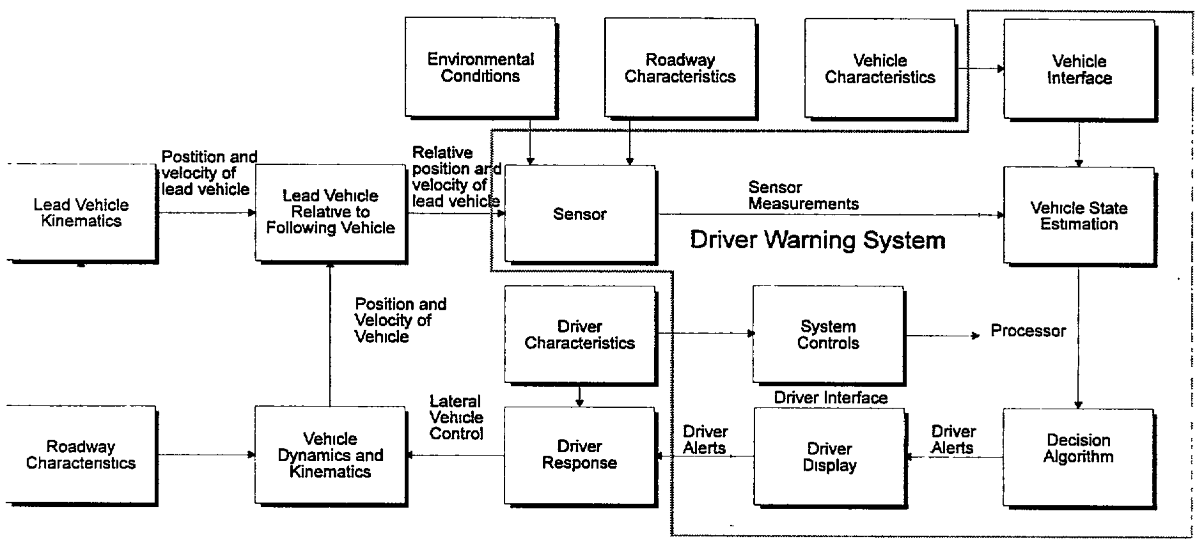

Figure 1 Driver Warning System Block Diagram

The major components of the system are Sensor, Processor and Driver / Vehicle Interface, refer to Figure 1. The sensor is the device that senses or detects objects in the vehicle's forward path. The processor receives information from the sensor and analyzes the information to determine what action, if any, is needed. The driver / vehicle interface presents the results of the analysis to the driver or vehicle in a comprehensible manner.

HUMAN FACTORS DEVELOPMENT

The University of Iowa, Center for Computer Aided Design, is performing Human Factors work for this program. The scope of the Human Factors Work is to develop the driver interface, perform human factors field testing and driving simulation experiments for all three system types.

Driver interface development has established a methodology for design of the driver-to-system interface. This includes delineation of basic system function and operation using Function Analysis, assessment and assignment of each system function using Function Allocation, identification of the system functions that are manipulated by the driver including all contingencies using Task Analysis, and Trade Studies to provide the design with display and/or system design options. This methodology can be used to evaluate other types of interfaces or interface options.

Field display modality studies have been performed to determine which individual warnings and/or combination of warnings was the most effective. Iowa Driving Simulator tests have been performed to measure drivers reaction to the interface under potentially emergency conditions as well as benign conditions.

MATHEMATICAL MODELING AND SIMULATION DEVELOPMENT

A math model has been developed for the rear-end collision avoidance problem. This computer simulation is used to simulate the countermeasure system design, as well as for performance evaluation and verification of system specification issues.

The math modeling and simulation works with all dynamics and kinematics of the lead and following vehicles. The simulation is a six degree of freedom (3 distance, 3 angle) environment with curved roads and multiple lanes. The simulation can be monte carlo or deterministic and includes random estimations for driver reaction time, vehicle braking deceleration and sensor errors. System effectiveness is the performance measure. The simulation can be used to assess performance of other system types as well.

The simulation establishes the preliminary requirements for detection range, range rate measurements, state estimation, filter bandwidths, angle (field of view), allowable errors, allowable noise and false alarm rate.

SPECIFICATION DEVELOPMENT

Research and development in human factors, math modeling and simulation as well as on-road testing was used to develop the performance specifications. The specifications include information and data on dynamic situations, environmental conditions, roadway characteristics, vehicle characteristics, driver characteristics and system characteristics as they relate to rear-end collision avoidance systems.

Table 1 shows a list of the preliminary specifications developed for Driver Warning Systems. These are broken into required and recommended items where the required items must be included in the system. The actual performance specifications that will be available at the Peer Review Workshop contain additional insight into the basis of these specifications as well as further definition of the intent of the individual specification items.

Table 1 Driver Warning System Specifications

Description	Specifications
Driver Visual Display	Cautionary and imminent warnings
Minimum Cautionary Warning Time	1.6 seconds
Minimum Imminent Warning Time	0.9 seconds
Minimum overall height	TBD mm
Minimum warning band height	TBD mm
Minimum width	TBD mm
Maximum horizontal angle	15^{0} (from driver's normal line of sight)
Maximum vertical angle	15^{0} (from driver's normal line of sight)
Driver Visual Display	Graduated perspective visual display
No display	**> 2.4** seconds
Safe Display	$1.6 < t < 2.4$ seconds
Recommended Color	Green
Minimum Intensity	TBD
Caution Display	$1.1 < t < 1.6$ seconds
Recommended Color	Amber
Minimum Intensity	TBD
Warning Display	$0.9 < t < 1.1$ seconds
Recommended Color	Red
Minimum Intensity	TBD
Imminent Warning Display	$t < 0.9$ seconds
Recommended Color	Red (flashing)
Required Duty Cycle	4 Hertz rate
Minimum Intensity	TBD
Driver Auditory Display	Cautionary and imminent auditory warnings
Minimum Cautionary Warning Time	1.6 seconds
Recommended Tone	TBD Hz
Recommended Voice	"Look ahead"
Minimum Level	TBD dB above ambient noise
Minimum Imminent Warning Time	0.9 seconds
Recommended Voice	"Brake"
Minimum Level	TBD dB above ambient noise, cautionary warning override
Cadence and Tone	TBD

Driver Haptic (Tactile) Display	TBD
Cautionary Display Modality	TBD
Minimum Cautionary Warning Time	t <1.1 seconds
Imminent Display Modality	TBD
Minimum Imminent Warning Time	t < 0.9 seconds
Driver Adjustments / Controls	Recommend none, no adjustments below minimum warning times
Prime Power Input	9 Volts to 16 Volts (12 Volts Nominal)
Sensor Beam	Multi-Beam or Scanned
Horizontal Field of Regard	± 8 degrees
Horizontal Angular Resolution	TBD degrees
Vertical Field of Regard	2-3 degrees
Detection Range	>130 meters
Measured Range Error	Largest of 0.07*Range or 0.7 meters
Measured Range Noise	Largest of 0.04*Range or 0.4 meters in a 2 Hz Bandwidth
Measured Range Rate Error	Largest of 0.025*Range or 0.4 m/s
Range Rate Resolution	0.4 meters/second
Measured Range Rate Noise	0.13 meters/second in a 2 Hz Bandwidth
Speed Measurement Error	0.4 meters/second
Speed Measurement Noise	0.07 meters/second in a 2 Hz Bandwidth
False Alarm Rate	1 x 10 / second
Nuisance Alarm Rate	< TBD
Early Alarm Rate	< TBD
Miss Rate	0
System Delay Time	< 300 milliseconds
Travel Speed	16 kph to 105 kph
Data Sampling Rate	> ten times minimum bandwidth
Environmental Conditions	No degradation
Traffic Conditions	No degradation
Roadway Conditions	No degradation, adaptable
Driver Characteristics	No degradation, adaptable
Vehicle Characteristics	No degradation, adaptable
Waterproofing	Within mounting environment
Operating Temperature	-40°C to +100°C
Storage Temperature	-55°C to +125°C
Relative Humidity	0 to 95% non-condensing over operating temp
Condensation	No degradation, over operating temperature range
Water, Snow and Ice Build up	No degradation
Altitude	- 100 meters to +4573 meters operating -100 meters to +12,192 meters storage
Fluid Exposure	No degradation, in mounting environment

NOTES

The specification presented at the Peer Review Workshop is intended to define required performance criteria for forward looking driver warning collision avoidance systems. Two other preliminary performance specifications exist, an Automatic Control System and an Adaptive Cruise Control System Specification.

Automatic Control Systems would take temporary control of the vehicle to avoid a dangerous situation for which th edriver has not sufficient time to react. An Automatic Control System monitors the forward path of the host vehicle and provides temporary control, such as braking and/or steering to avoid a collision. The Automatic Control System provides indication to the driver that the system has taken temporary control. The Automatic Control System may work as an extension of the Driver Warning System, or it may be a stand alone system.

Adaptive Cruise Control (or Intelligent Cruise Control) systems allow the driver to select a cruise control feature that tracks the vehicle in front of the host vehicle and automatically maintains a safe headway. When no vehicles are present, the host vehicle maintains a set speed. If the headway between the host vehicle and the vehicle in front falls below the safe headway, the system initiates control actions (such as accelerator release, or braking) to slow the vehicle and reestablish a safe headway. The system should warn the driver (who must then take action) when the system is incapable of reacting to the current situation. The warning / suggestion can be either imminent or cautionary through a visual display which must be accompanied by a supplemental auditory warning and can be accompanied by supplemental haptic (tactile) indications.

This document was specifically written for the Peer Review Workshop, and provides contract overview as well as insight into the preliminary performance specifications that have been developed. Additional information is contained within the actual specifications that will be available at the Peer Review Workshop. The specifications are preliminary and will continue to be updated as part of the progress on this NHTSA sponsored contract. As a result, it is highly desirable that feedback be provided in relation to any and all items contained within the specifications. Information may be provided to:

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Collision Avoidance System Performance Specification for Lane Change, Merging and Backing: Phase I Results and Future Plans

Stephen K. Young
TRW Space and Electronics Group

1.0 Introduction

The objective of the NHTSA-funded study at TRW is to determine the performance specifications of collision avoidance systems (CAS) for lane change, merging and backing. This four-year effort was initiated in the summer of 1993 as one of four NHTSA programs whose overall goal is to demonstrate the enhancement of crash avoidance performance of vehicles through the application of advanced technology. It is hoped that these studies will serve as a catalyst to facilitate the development and availability of Intelligent Vehicle Highway Systems (recently renamed Intelligent Transportation Systems or ITS) safety technologies. The early development of performance guidelines will also lessen the risk of hazardous side effects and help ensure that safety enhancement goals are achieved.

The program is subdivided into three phases. Phase I lays the foundation for the study through the execution of four tasks, namely:

<u>Crash Problem Analysis</u>. The crash problem is analyzed through an examination of the lane change, merging and backing accidents as described in the national accident data bases. The crashes are classified into taxonomies. The various crash types are ranked by their frequency of occurrence and by their associated fatal crash equivalents (FCEs). Causal factors, if any, for the crashes are gleaned. Vehicle kinematics and driver actions, where available, are extracted. Crash avoidance opportunities are identified.

<u>Functional Goals Establishment</u>. Changes to the crash situations, which would have helped to eliminate the studied accidents or to reduce their severity are known as functional goals. These functional goals for the CAS under study are identified. In general, these goals include changes and/or additions to the roadway infrastructure as well as to the vehicle. However, the current program emphasizes the latter.

<u>Existing Hardware Svstem Testing</u>. Available CAS, including off-the-shelf commercial products as well as prototypes are tested. This provides a broad overview of current CAS capabilities vis-a-vis the established functional goals. Moreover, human factor experts can get some preliminary indications as to what constitutes desirable driver-vehicle interface (DVI) features and to check these observations against recently established preliminary human factor guidelines. (Reference 1) Finally, test methods and data analysis tools are developed.

Preliminary Performance Specifications. Through a combination of analytical studies, computer simulations and use of a driving simulator, preliminary performance specifications for each of the identified functional goals are obtained.

Phase I was completed in June, 1995. We are currently in Phase II in which advanced technologies potentially applicable to crash countermeasures are being evaluated. A testbed which allows the test and evaluation of technologies and systems will be designed. In Phase III, this testbed will be constructed and used to refine the preliminary performance specifications obtained in Phase I. Finally, the effectiveness of CAS which meet these performance specifications will be estimated using test data and analyses. The program is scheduled for completion in the Fall of 1997.

Besides the Space and Electronics Group of TRW, the team includes Systems Technology, Incorporated (STI) at Hawthorne, California and the University of Texas at San Antonio (UTSA). STI provided overall program support in human factors and conducted driving simulator studies with test subjects. UTSA provided support to the Crash Problem Analysis task, through its familiarity with the accident data bases and its expertise in statistical analysis. Finally, hardware testing on existing systems was performed at the Vehicle Research and Test Center (VRTC) in East Liberty, Ohio. Test support was provided by VRTC and Transportation Research Center (TRC), Inc. VRTC also conducted the human factor portion of the tests.

In the following sections, Phase I results are summarized, culminating in the preliminary performance specifications for a lane change CAS.

2.0 Crash Problem Analysis

A detailed analysis of the 1992 national accident data bases reveals the following classifications of lane change, merging and backing crashes. The taxonomies for lane change and merging are shown in Figure 1. Data bases employed include the General Estimate System (GES), Crashworthiness Data System (CDS) and the Police Accident Reports (PAR). The GES, being representative of all accidents nationally in a given year, provides the most significant statistics for assessing the relative significance of the various crash types and for the identification of association between specific conditions and crash occurrence. The CDS provides additional data on the more severe crashes, i.e. those requiring at least one vehicle to be towed. Of particular interest is the data necessary to create crash scenarios including the crash kinematics. The PARs further supplement the CDS, particularly in backing crashes, which often do not make it into the CDS due to the lesser vehicle damage associated.

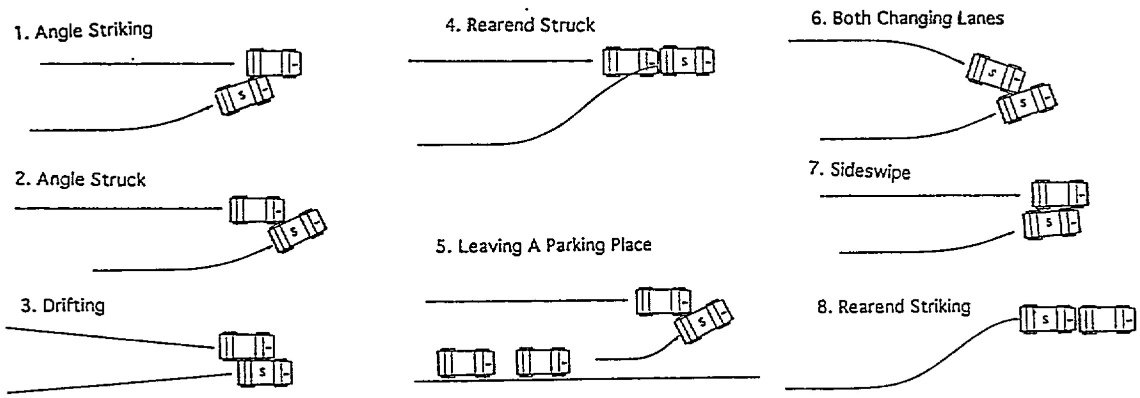

Figure 1. Lane Change/Merge Crash Classifications

The above taxonomies include the "rear-end striking" and "rear-end struck" categories. These collisions though relatively infrequent (5% and 4% respectively of all lane change/merge crashes) are significant in terms of fatal crash equivalents (FCEs)*, with "rearend striking" accounting for 20% of the total FCEs. (See Figures 2 and 3). The elimination of these crashes can lead to potentially large payoff for CAS. Similarly, the most significant crash types in terms of FCEs for backing crashes involve vehicles in "crossing path" geometries where the backing vehicle is struck by a high speed vehicle in an orthogonal trajectory. (See Figures 4 and 5.)

- 300,320 (standard error 23,236)
  - 5.0 % of the 5,982,606 police reported crashes based on the 1992 GES elecetronic database

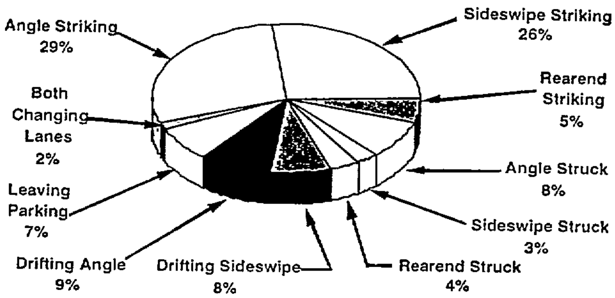

Figure 2. Lane Change/Merge Population Summary

1,627 Fatal Crash Equivalents (FCEs) => $5.3 billion

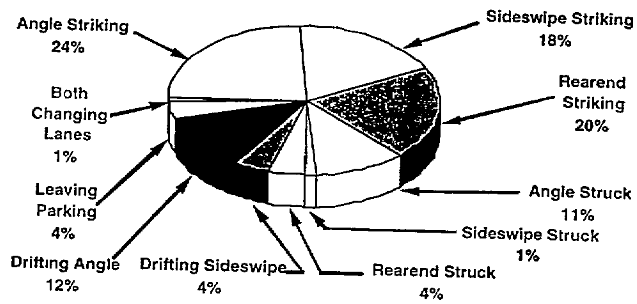

Figure 3. Lane Change/Merge FCE Summary

- 232,844 (standard error 18,641)
  - 3.9 % of the 5,982,606 police reported crashes based on the 1992 GES elecetronic database

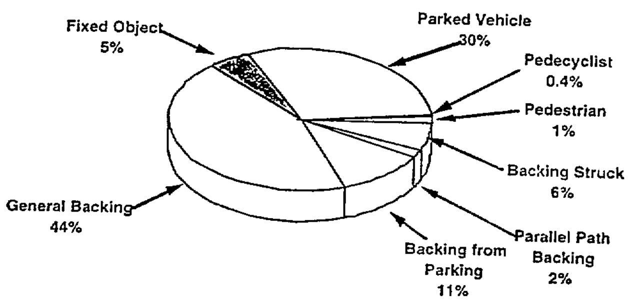

Figure 4. Backing Population Summary

- 681 Fatal Crash Equivalents (FCEs) => $2.2 billion

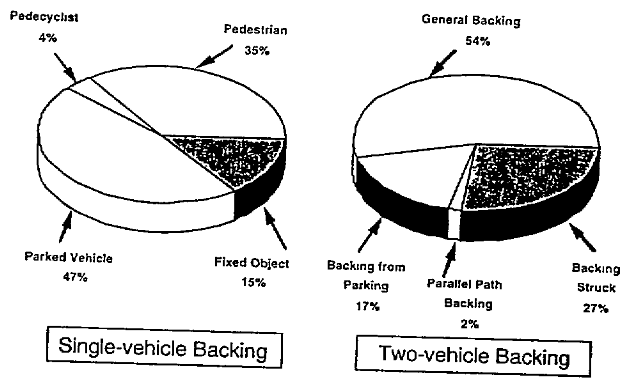

Figure 5. Backing FCE Summary

No consistent pattern of association has emerged between specific conditions and crash occurrence. There appears to be a potential correlation between compromised lighting and alcohol use with crash occurrence when only the more severe crashes (as measured by FCEs) are considered. However, further studies are required in order to confirm that these are indeed correlations rather than aberrations caused by some unknown hidden variables. One factor does emerge from the study. In 86% of the 1992 GES lane change, merge and backing crashes, the drivers did not attempt any crash avoidance maneuvers. This points to driver inattentiveness as the major cause for the crashes and bodes well for the usefulness of a warning system.

Finally, as an example of the kinematics data that we can glean from the crash data bases, we show below the closing speed distributions for some categories of lane change, merge (Figure 6) and backing crashes (Figure 7). These distributions are important in computer simulations for determining the performance specifications of CAS and in estimating CAS effectiveness. (In Figure 6, low SV speed refers to speeds less than 20 mph, high speeds are over 50 mph and medium speeds are between 20 and 50 mph.)

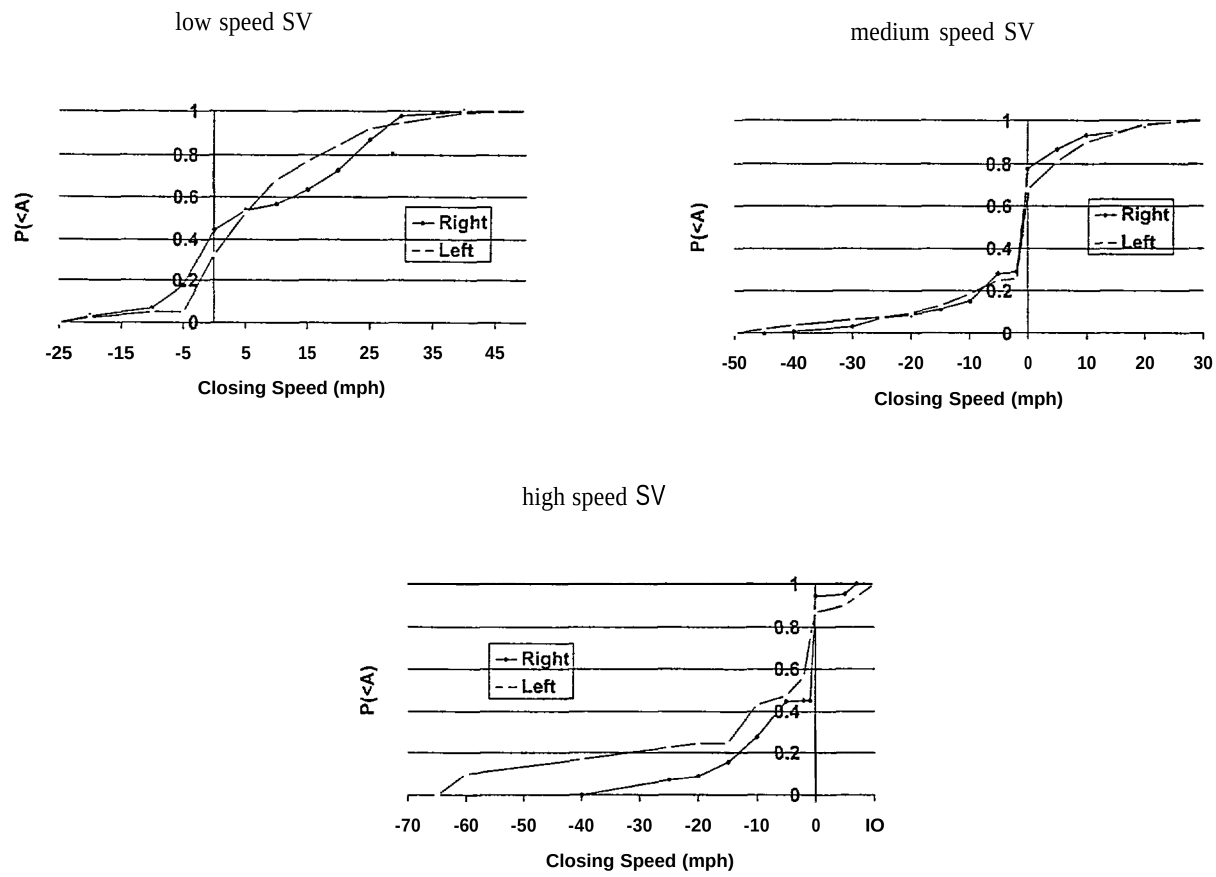

Figure 6. Closing Speed Distributions for Lane Change and Merging Crashes derived from the '92 GES

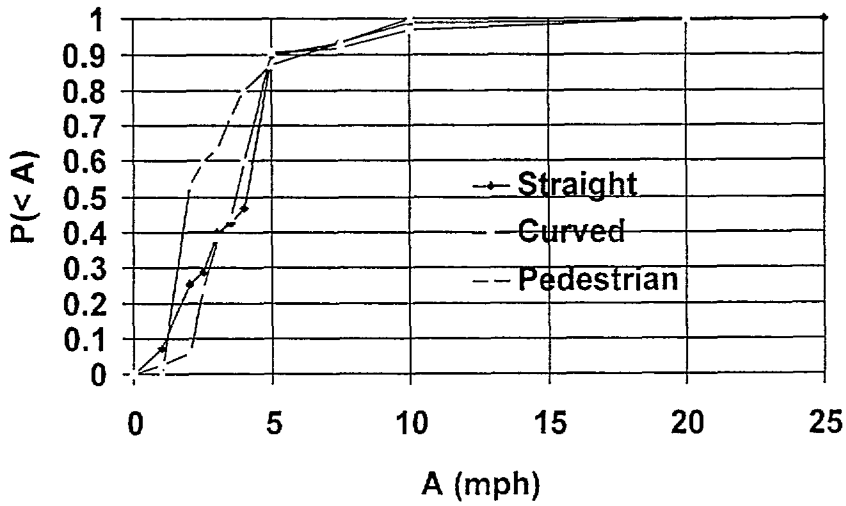

Figure 7. Backing Vehicle Speed Distributions from '92 GES and PARs

3.0 Functional Goals Establishment

The taxonomies developed above allow top level functional goals to be established for the various crash types. These goals are changes to the crash situation brought about by the CAS which would result in the elimination of the crash or the reduction in the crash severity.

The major functional goals for lane change CAS include 1) monitoring/warning of potentially conflicting vehicles in the "blind spots", 2) monitoring/warning of fast-closing and potentially conflicting vehicles in the adjacent lanes, both fore and aft of the subject vehicle, 3) detection of inadvertent vehicle drift over to adjacent lanes. The first functional goal is being addressed by all existing systems. The "blind spot" crashes involve vehicles with low closing speeds, which indeed characterize most of the lane change crashes. We define closing speed as the difference in speeds between the principal other vehicle and the subject vehicle. A majority (58%) of all 1992 GES lane change crashes have closing speeds less than 5 mph. Closing speeds of 0, 15 and 30 mph characterize 38, 78 and 94 % respectively of all lane change crashes. The second functional goal of warning against fast-closing vehicles deals with a relatively small number of collisions. Yet the high closing speeds lead to higher FCEs. This goal represents crash avoidance opportunities previously unexploited but is within reach of current technologies. Indeed, it is being addressed by several emerging systems. A pictorial representation of the functional goals is depicted in Figure 8.

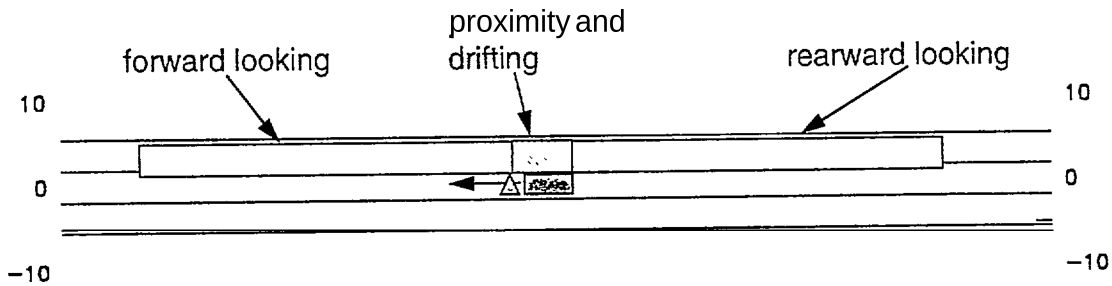

Figure 8. Lane Change Functional Goals

Major functional goals for backing CAS include 1) detection of rear obstacles in close proximity to the subject vehicle, 2) detection of crossing path pedestrians, pedacyclists and vehicles in the rear, and, 3) detection of crossing path backing vehicles in the forward path of the subject vehicle. The second goal has been noted in previous studies (Reference 3) but little discussed. The third goal can be viewed as an extension of the functional goal of a forward collision warning aid. However, its wide field of view requirement is similar to that found in CAS required to mitigate against crashes at intersections. Current systems address only the first functional goal. Again, there are significant opportunities for enhancing vehicle safety by the use of advanced technologies. However, functional goals 2 and 3 present major technological challenges to system design.

4.0 Existing Hardware System Testing

Over a period of about one year from June 1994 to April 1995, a total of eleven existing CAS were tested at VRTC. The purpose of these tests was to assess current CAS capabilities and to examine the extent to which they meet the functional goals identified. Some of these systems are commercially available while others are developmental prototypes. The sensor technologies employed by these systems include acoustic, radar and electro-optical. The DVI of these systems range from the relatively sophisticated displays in the commercially available systems **to** the primitive displays found in some prototypes.

There was no intention of ranking these systems nor was there any attempt at unraveling the detailed operational principles and algorithms. Testing was performed on each system at VRTC and its environs. Tests comprised laboratory characterization, static detection pattern measurement and characterization, controlled track tests and road tests in city streets, arterial roadways and interstates. Two vehicle platforms, a Honda Acura and a High Mobility Multi-Wheeled Vehicle (HMMWV), were employed. TRW performed the sensor testing while VRTC evaluated the DVI aspects of these systems. Two human factor experts drove the systems during daylight and evening hours, using a “human factor checklist” methodology developed by

COMSIS for CAS evaluation **on** heavy vehicles and modified by VRTC for the current program.

Using video cameras as truth sensors, various characteristics of the systems were extracted. One such characteristic is the system latency, which denotes the delay between when the potential conflicting vehicle enters the field of view to the time when the appropriate warning is issued. It encompasses the observation and processing times and is a key system parameter. When this latency is taken into account, one can correlate the static detection patterns of the systems with those obtained while the host vehicle is in motion.

At the system level, performance of the CAS can be characterized by the percent of true positives, false positives, false negatives and true negatives. A true positive is a detection when there is an appropriate target. A false positive is a detection when there is no appropriate target. A false negative is the absence of a detection when there is an appropriate target. A true negative is the absence of a detection when there is no appropriate target. An appropriate target is one that poses a potential collision threat.

All but one tested systems are simple proximity (< 5 meters) detectors. Those which claim to discriminate against ground clutter did so with only fair results. The performance capabilities of systems vary widely, e.g. the measured system latency ranges from 40 to 1900 ms. Test data indicate that the measure of true negative response of the system could be a useful metric to judge the relative effectiveness of the systems tested.

The human factor testing of these existing CAS produced results that are consistent with published preliminary human factor guidelines. A list of some possible desirable design features are included in Table 3 below. These features do not, however, reflect a thorough assessment of the driver’s need, nor are they expected to be the final guidelines which will be developed on the current project.

5.0 **Preliminary Performance Specifications**

For the purpose of this overview document, we will focus our discussions on collision avoidance systems for lane change, hereafter referred to simply as the CAS. The CAS is resident on the host or subject vehicle (SV). SVs include cars, trucks, buses and tractor trailers. The target or principal other vehicle (POV) includes all the above vehicle types plus motorcycles and bicycles.

Top Level Reauirements

The performance specifications are flowed down from the top level requirements for the CAS. These are:
- to detect potentially conflicting vehicle(s) before and/or during a lane change maneuver by the SV, and,
- to warn the driver in time to avert the impending accident or to alleviate its severity.

Furthermore, the CAS
- must satisfy all host platform constraints, including electrical, mechanical and environmental constraints,
- must not interfere with the operation of other in-board and out-board system,
- must accommodate all physically-realizable vehicle dynamics in terms of velocities and accelerations for both the SV and the POV,
- must operate under all weather, day and night, conditions normally encountered in the U.S.,
- must operate under all road geometries, including grades, curves and road types, encountered in normal driving within the U.S., and,
- must accommodate licensed drivers of all ages.

Cost of the final commercial product is not a top level requirement in the current study. However, in the requirements flow down process, cost is factored into our consideration for technology feasibility.

Block Diagram for the CAS

In general, a CAS consist of the sensor, the processor and the warning display as **shown** in Figure 9, which also depict interactions between the CAS, the driver, the vehicle and the collision threat. When activated, the sensor takes in energy from the monitored scene. The signal is processed by the processor, which extracts the potential target(s) from the background scene and measures its (their) attributes. Based on a set of algorithms or criteria, the processor activates the warning display, which will provide the appropriate warning to the driver in the form of a visual, audio or haptic signal. In the case of those CAS that take automatic control of the vehicle, the processor would (under prescribed conditions) issue a signal to initiate automatic vehicle action. In our Phase I effort, we have not considered this class of automatic systems. In general, the processor interfaces with the vehicle in a passive mode. It receives vehicular data, e.g. velocity, for target discrimination and in the case of on-demand operation, it receives an activation signal triggered by a selected mechanism, such as the activation of the turn signal.

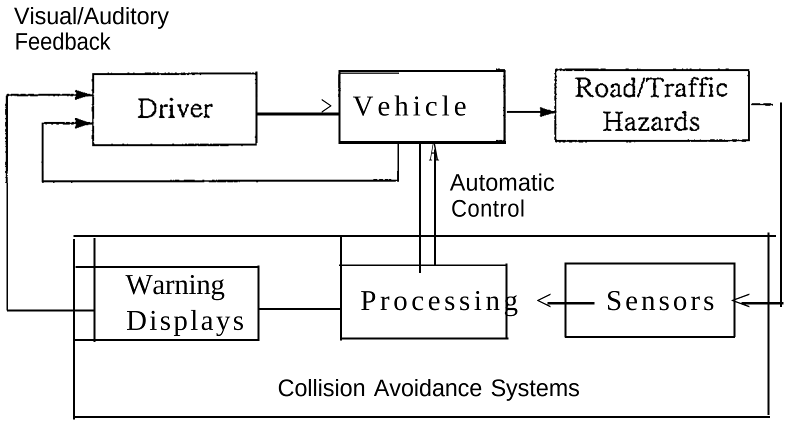

Figure 9 - CAS Interfaces

Requirements Flow-down Methodology via Simulations & Test

The functional goals described in 3.0 above provide further specifics for the detection function to include target vehicles in the "blind spot" as well as those that have fast closing velocities relative to the SV. These are considered the most significant targets in terms of frequency of occurrence and the severity of the accidents.

Two simulation approaches have been used to analyze the performance specifications for these lane change functional goals. The Monte Carlo simulation and the driving simulation are described briefly below.

A Monte Carlo simulation models the lane change process for actual lane change accident scenarios gleaned from the 1992 GES. Velocities of the SV and the POV are sampled from the observed travel speed distributions found in the GES database and the associated police reports. The code assumes that the driver is unaware of the surrounding traffic and determines if the warning issued by the CAS would assist the driver in avoiding the collisions. The simulation accounts for a distribution of driver response characteristics (e.g. control timing) and conflict variables (e.g. closing speed and initial gap distance). It determines, in a statistical fashion, the fraction of accidents avoided, for a given set of CAS performance parameters such as sensor detection pattern (range, azimuth, elevation) and system latency.

The driving simulator is a PC based, interactive driving simulator designed by STI to enable driver behavior research and rapid prototyping of new systems. This fixed-base simulator includes vehicle dynamics, computer-generated roadway display, auditory cueing for vehicle and roadway environmental sounds, control cueing based on vehicle maneuvers to command steering torque, instrument cueing to drive a speedometer, and elements for controlling driving scenarios, collecting data and calculating performance measurements. To this simulator is added the CAS model with the sensor and processor characteristics identical to those used in the Monte Carlo simulation and driver warning display interfaces. Subjects are exposed to driving scenarios with potential traffic conflicts in the interactive simulator. Actual conflicts depend on the driver's situational awareness, which is assisted by rear view mirrors and CAS displays. While the Monte Carlo focuses on the actual conflicts, the driving simulator focuses on the driver's reaction to the warning/display format in a dynamic traffic situation.

Finally, the test of existing hardware systems described in 4.0 above by human factor experts at VRTC provides further indications as to what are ergonomically desirable or undesirable CAS-driver interfaces. Though limited to available systems and designs, these tests nonetheless provide data that generally support the validity of currently available preliminary human factor design guidelines. (Reference 1)

Preliminary Performance Specifications for a Lane Change CAS

We summarize below key performance specifications for 1) a minimal lane change CAS, i.e. a proximity or “blind spot” detector, and 2) a counter-fast-approach adjunct to the minimal system. A combination of 1 and 2 provides a “complete” CAS. The proximity sensor warning would only rely on target presence in the “blind spots” but the counter-fast-approach system would base its warning on both the range and the relative velocity of the POV.

Human factor related “specifications” are only available as preliminary guidelines or indications due to the limited testing and simulations that have been performed during Phase I. These are summarized in Table 3. Results of this and other related effort (Battelle project) will be synthesized at the end of the program for the eventual display/warning specifications.

Table 1. Key Preliminary Performance Specifications for a “Blind Spot” Detector

Description	Specifications
Function	target detection in specified zone; driver alert
Sensor Coverage	1 lane (3.7 meter) to left or right in the transverse direction; 1 vehicle length in the longitudinal direction; 0.3 meter - 3 meter in height
Size of Target	from pedacycle to truck
Target Velocity	any allowable
Target Acceleration	any achievable (-g to +g)
Number of Targets	multiple, most likely one at a time
Host Platform Velocity	any allowable
Host Platform Acceleration	any allowable
System Latency	< 500 ms
Measurement Accuracy	0.6 meter
Probability of Detection	> 0.99 (TBR)
Probability of False Alarm	< 10[illegible] (TBR)
Probability of Nuisance Alarm	< 10[illegible] (TBR)
Duty Cycle	on demand operation with TBD activation mechanism

Table 2. Additional Performance Specifications to the "Blind Spot" Detector to Counter-Measure against Fast Approach Collisions

Description	**Specification**
Function	Longitudinal velocity measurement of target vehicles
Coverage	Coverage in the longitudinal direction to 25 meter (TBR) fore and aft of the SV
Relative (Closing) Velocity Range	+/- 100 kph
Number of Targets	One or more targets per zone
Relative Velocity Measurement Accuracy	+/- 1.5 m/s

Table 3. Key Preliminary Human Factor Guidelines from Reference 1 for a "Blind Spot" Detector. Where applicable, desirable features indicated in our Phase I testing that are in concert with the guidelines are also included.

Description	**Guidelines/Desirable Features**
Number of Warning Modes	• Present imminent crash avoidance warning in 2 modes. One mode must be visual and one must be audio or tactile. Activation of the turn signal is sufficient to define an imminent crash situation • Cautional warnings should be presented visually. Desirable Features: Provide audio warning only when the turn signal is on (or there is some reason to expect that the driver is about to steer the vehicle to either the left or right); Provide no more than 2 levels of warning
Display Location	Primary visual display should be located at or within 1.5 degrees vertically above the line of sight of the side view mirror on the same side of vehicle as the related detector system. The visual indicator must be located at, or within 15 degrees horizontally forward of, the line of sight of the side view mirror. Desirable features: Has the driver warning display located on or near the line of sight to the appropriate side view mirror.

Device Testing & Status Indicators	Capable of built-in diagnostic testing, failure indication and manual test of warning displays • provide status display located separate from warning display • provide manual adjustment of display intensity (e.g. volume, brightness) Desirable Features: • Has 2 visual displays. These are a driver warning display and a system trouble display. • The system trouble visual display should be integrated with the vehicle's instrument panel. • Allow loudness of audio display to be adjusted. • Allow brightness of the visual display to be adjusted. Automatic adjustment may be best. • Manual loudness and brightness control should be located on the vehicle's instrument panel. • When the controls are used to manually adjust loudness or brightness, the interface should momentarily produce a warning signal so as to provide the operator with feedback about the adjusted level.
Cautionary Warning Characteristics	• Use continues red for systems with one level of cautionary warning • Indicator lights should subtend a minimum angle of 1 degree • There should be no display if no target or critical situation is sensed. Desirable Feature: Has the driver warning visual display indicate presence of an object in the detection zone by turning on a red light and turning off all other lights on this display.

Auditory Imminent Warning	Characteristics • fundamental frequencies: 500 - 3000 Hz recommended • spectral characteristics: complex sound should be used as opposed to pure sinusoidal waveform • intensity: at least 20dB but no more than 30dB above the masked threshold • directionality: consistent with the direction of the hazard • onset and offset rates: onset rates > 1 dB/ms but less than 10 dB/ms; offset rates should equal onset rates • warning duration: 200 - 500 ms for single sound or tone; 200 -300 ms for complex tones • warning repetition: single sound or tone to be repeated as long as crash avoidance warning condition exists
Visual Imminent Warning Characteristics	• prominent, rapidly flashing red indicator • flash rate of 5 Hz with equal on and off times
Status Indicator Characteristics	• provide positive indication of power to the device • use Green to indicate that device is turned on and has passed diagnostic test • use Red or Yellow/Amber to indicate that the device is turned on but is not functioning properly
Multiple Warnings	• present all crash avoidance warnings simultaneously, regardless of thei priority . present the highest priority warning by means of an acoustic or tactile display • provide driver cueing to the highest priority warning indicated, e.g. via the directional nature of the warning indication

6.0 Epilogue

The preliminary performance specifications presented in this draft document are a subset of the specifications developed for all the lane change functional goals identified. Preliminary specifications for systems meeting all the functional goals for lane change, merging and backing collision avoidance systems exist and they will be available at the Workshop. Additional details to support the development of the specifications will also be provided.

We must emphasize that these specifications are preliminary in nature and they will be updated as the current NHTSA sponsored contract progresses. To maximize the productivity of the Workshop, feedback prior to the Workshop on any of subjects discussed in this overview document are welcome.

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Program Overview: Run-Off-Road Collision Avoidance Using IVHS Countermeasures

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INTRODUCTION

The Run-Off-Road Collision Avoidance Using IVHS Countermeasures program is a four year program sponsored by the National Highway Traffic Safety Administration (NHTSA). The prime contractor for this effort is Carnegie Mellon University (CMU). Members of the project team include Battelle Memorial Institute, Calspan Corporation and the University of Iowa. The primary goal of the program is to develop practical performance specifications for roadway departure collision avoidance systems.

The program is divided into three phases. Phase I was recently completed, and involved the following four activities:

- Analyze the roadway departure crash population to determine frequency and circumstances associated with roadway departure crashes.
- Identify opportunities for intervention in the crash sequence and develop functional goals which a countermeasure could perform to prevent the crash.
- Test existing systems for preventing roadway departure crashes
- Develop mathematical models of potential countermeasure systems and use these models to develop preliminary performance specifications.

Phase II of the program will consist of two primary activities:

- Review state-of-the-art sensing, processing and driver interface technologies for their applicability to run-off-road collision prevention
- Design an advanced testbed vehicle for evaluating alternative countermeasures.

Phase III of the program will involve the following efforts:

- Construct testbed vehicle
- Conduct and document tests of alternative countermeasure systems
- Develop and publish technology independent performance specifications for roadway departure collision avoidance systems based on tests results.

RUN-OFF-ROAD PROBLEM CHARACTERIZATION

Run-off-road crashes are defined to be all single vehicle crashes where the first harmful event occurs off the roadway, except for backing and pedestrian related crashes. A statistical review of the 1992 General Estimation System (GES) and Fatal Accident Reporting System (FARS) databases indicate that run-off-road crashes are the most serious of crash types within the national population. The crashes account for over 20% of all police reported crashes, and over 41% of all in-vehicle fatalities (15,000 / year). Some of the most important roadway departure crashes are the following:

- They occur most often on straight roads (76%)
- They occur most often on dry roads (62%) in good weather (73%)
- They occur most often on rural or suburban roads (75%)
- They occur almost evenly split between day and night

Unlike many of the other crash types, run-off-road crashes are caused by a wide variety of factors. Detailed analysis of 200 NASS CDS crash reports indicates that run-off-road crashes are primarily caused by the following six factors (in decreasing order of importance):

- Excessive speed (32.0%) - traveling too fast to maintain control
- Driver incapacitation (20.1%) - typically drowsiness or intoxication
- Lost directional control (16.0%) - typically due to wet or icy pavement
- Evasive maneuvers (15.7%) - driver steers off road to avoid obstacle
- Driver inattention (12.7%) - typically due to internal or external distraction
- Vehicle failure (3.6%) - typically due to tire blowout or steering system failure

COUNTERMEASURE FUNCTIONAL GOALS

The wide range of causal factors and circumstances surrounding run-off-road crashes suggest that no single functional goal will serve to prevent these crashes. Instead, careful analysis indicates that three sets of parallel functional goals are necessary (and sufficient) to address most roadway departure crashes. A block diagram depicting how these functional goals could be combined into an integrated run-off-road countermeasure system is shown in Figure 1.

As can be seen from the block diagram, the functions performed by the integrated countermeasure can be divided into three categories: sensing functions, processing functions and driver interface functions. Within the sensing and processing functions, there are three parallel functional sequences each leading to the issuing of an alert to the driver.

The first of these parallel functional sequences involves detecting dangerous impairment of driver state. If the driver is drowsy, intoxicated, or in some other way impaired, this sequence is intended to detect the situation and trigger a sequence of driver interface functions to prevent a crash. This functional sequence is included in the block diagram for completeness, but to avoid duplication of effort with the ongoing NHTSA driver impairment detection program, driver impairment detection has not been the focus of the Phase I efforts for this program.

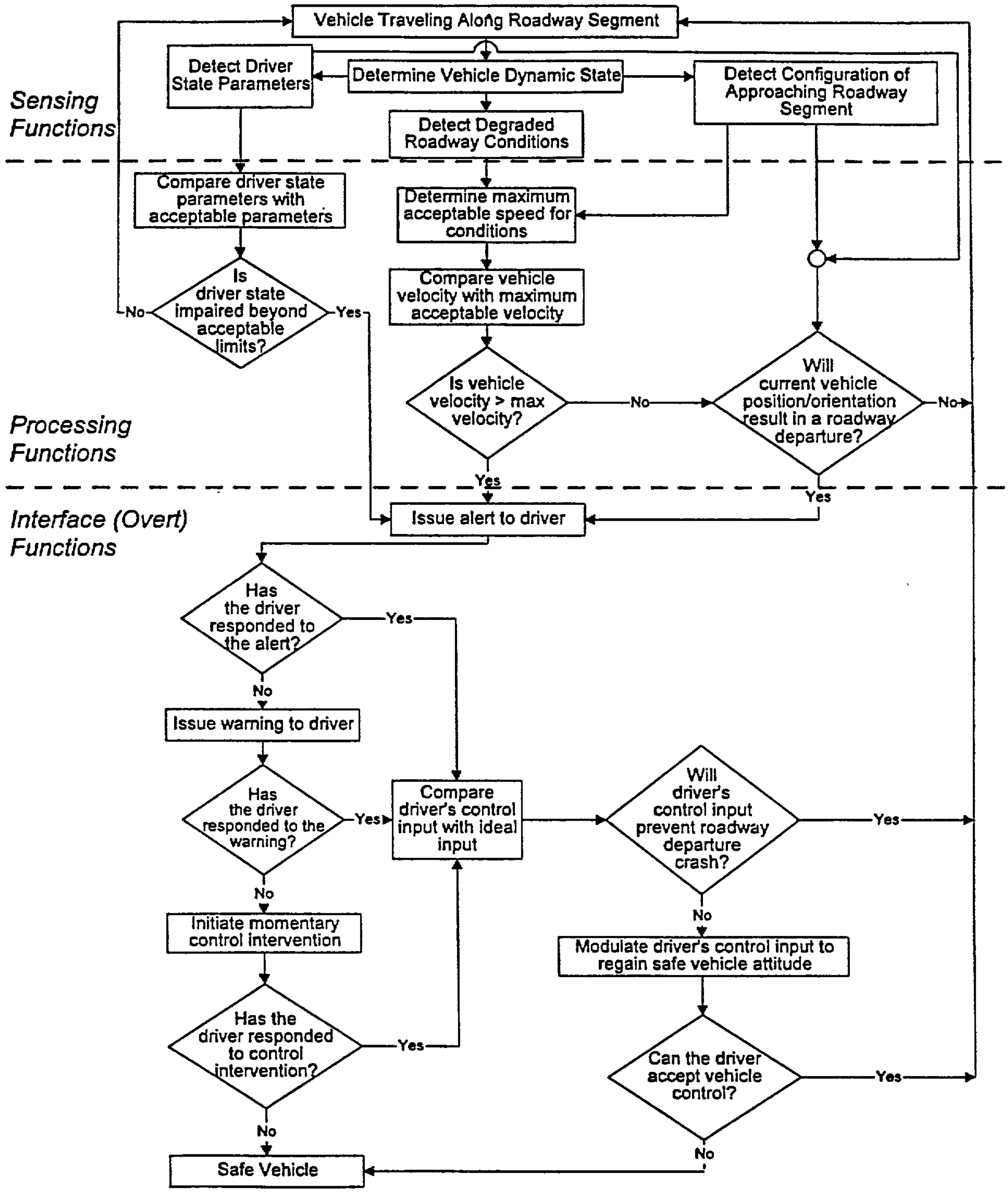

Figure 1. System Functional Goals

Instead, the Phase I efforts have focused on testing systems for the other two functional sequences, which are termed “longitudinal” and “lateral” sequences. In the longitudinal sequence, the goal is to detect when the vehicle is traveling too fast for the upcoming roadway segment. The longitudinal sequence utilizes vehicle dynamic state and performance data in combination with information about the current pavement conditions and upcoming roadway geometry to determine the maximum safe speed for the vehicle. If the vehicle’s current velocity exceeds the safe speed, a sequence of driver interface functions is triggered to alert the driver of the danger and avoid a crash. The longitudinal functional sequence is designed to prevent those run-off-road crashes caused by excessive speed and lost directional control.

The lateral functional sequence is designed to detect when the vehicle begins to depart the road. It utilizes data about the dynamic state of the vehicle, in combination with information about the geometry of the road ahead to determine if the vehicle’s current position and orientation will likely lead to a roadway departure. If the likelihood of departure exceeds a threshold, a sequence of driver interface functions is triggered to alert the driver of the danger and avoid a crash. The lateral functional sequence is designed to prevent those run-off-road crashes caused primarily by driver inattention and driver relinquishes steering control.

It is important to note that two of the original six run-off-road crash causal factors identified in Task 1 are not addressed by these functional sequences. The first is crashes caused by evasive maneuvers in which the driver intentionally swerves to avoid an obstacle in the roadway, resulting in a roadway departure crash. It was determined that these crashes were largely being addressed by the rear-end collision countermeasures specifications program. Therefore, crashes caused by evasive maneuvers were eliminated from Phase I consideration of this program.

The second crash type not addressed by the functional sequences in the block diagram are crashes caused by vehicle failures. These crashes typically result from tire blowouts or loss of power steering due to engine failure. The analysis conducted from this program indicates that crashes from these causes are relatively rare (only 3.6% of the run-off-road crash population). In addition, countermeasures to prevent these crashes would require redesigning automotive components in a way that is beyond the scope of this program. For these reasons, crashes caused by vehicle failure have been eliminated from consideration in Phase I of this program.

TESTS OF EXISTING TECHNOLOGY

Having identified the functions a run-off-road countermeasure should perform, the next step in the Phase I effort was to test existing technology for performing these functions. The team’s technology search was unable to identify any existing complete countermeasure systems for either lateral or longitudinal run-off-road crashes which were available for testing.

To overcome this hurdle, the team acquired those commercially available components which could form part of a run-off-road countermeasure. These components were combined with technology developed “in-house”, either as part of this program or previous efforts, to form complete countermeasures for testing. In total, the team developed and tested four complete countermeasures, three lateral and one longitudinal system. Tests of these countermeasures were conducted both on a testbed vehicle develop for Phase I, and in simulation on the Iowa driving simulator.

In-Vehicle Tests

The three lateral countermeasures are designed to warn the driver when the vehicle begins to drift off the road. The first of these systems, called AURORA, uses a downward looking video camera to track lane markings next to the vehicle. AURORA determines the vehicle's position in the lane by measuring the distance between the vehicle's tires and the lane marking. Laboratory and in-vehicle tests of the AURORA system indicate that it can estimate the lateral position of the vehicle with about lcm accuracy. Tests showed AURORA to be relatively insensitive to ambient lighting and road condition. However AURORA is limited to roads with distinct painted lane markings, and has difficultly when the markings are severely degraded, obscured or missing. Also, downward looking systems like AURORA do not have forward preview capability, resulting in occasional false alarms when negotiating curves.

Two video-based lateral systems with forward preview capabilities were also tested, the ALVINN and RALPH systems. These two systems adapt their processing to the features available, and can therefore handle roads on which the lane markings are degraded, obscured, or missing. These two systems detect the road ahead of the vehicle in the video image, and can therefore anticipate curves better than AURORA. However, as systems with forward looking sensors, they are somewhat more sensitive than AURORA to harsh weather and lighting conditions. Tests showed that ALVINN can handle reduced visibility from rain and/or fog down to about 300m, but below that visibility level, performance begins to degrade. Other difficult situations for forward looking systems like ALVINN and RALPH are when the sun shines directly into the camera at dawn and dusk. Locating the road at night, using only headlights for illumination, was not a problem for these forward looking systems. Overall, the RALPH system was shown to be capable of locating the position of the road ahead of the vehicle to a distance of approximately 60m with an accuracy of about 12cm on a wide variety of road types and environmental conditions.

The longitudinal system developed and tested for this effort was designed to warn of excessive speed when approaching curves. The system consists of a Differential GPS for determining the vehicle's current position, and a digital map for estimating the distance to the upcoming curve and its severity. If the system detects that the vehicle is traveling too fast to safely negotiate the upcoming curve, it triggers an audible or tactile warning.

Experiments with the longitudinal system indicate that most of the technology exists for providing a reliable warning of excessive speed when approaching curves. Differential GPS can provide accurate and reliable estimates of the distance to an upcoming curve. Commercial digital maps, although currently not quite detailed enough, have the potential to provide the necessary geometric information regarding curve sharpness and superelevation. Tests of a system that combines information from GPS and digital maps show that is possible to provide reliable and highly repeatable warning signals (within 0.5 seconds) when approaching curves at excessive speed.

The biggest missing component for a general longitudinal countermeasure is an effective means of measuring degraded road conditions. Infrastructure-based pavement monitoring systems exist, but are expensive and provide data that is only valid in a local region. Simulation results of vehicle-based methods for inferring the coefficient of friction between the tires and the road appear promising, however these methods require the vehicle to encounter the degraded pavement before it **can** be detected. Further research is needed before a longitudinal countermeasure capable of handling all roadway conditions can be deployed. Fortunately, analysis of the national crash database indicates that only 10% of run-off-road crashes caused by excessive speed occur on snowy or icy roads. The remainder occur on pavement which is dry (64%) or wet (26%). A system that can simply detect whether the pavement is wet or dry has the potential to prevent most speed related roadway departure crashes.

Driving Simulator Tests

A crucial functional goal of all collision countermeasures is to effectively interact with the driver. A system must be capable of conveying the danger of collision to driver in a manner that elicits an appropriate response in emergency situations, and does not significantly increase the driver's workload during normal driving. Tests on the Iowa driving simulator suggest several interface configurations can achieve these goals. These tests included auditory warnings in the form of a tone, and/or haptic (tactile) feedback through the steering wheel (lateral system) or brake pedal (longitudinal system). Visual feedback was not considered since this form of interface would almost certainly be ineffective for a drowsy or distracted driver, and could potentially interfere with visual assessment of the situation just when such assessment is most crucial.

In general, neither the lateral nor the longitudinal countermeasures appear to significantly increase driver workload during normal driving. Either haptic or auditory interfaces appear to be viable means of providing the driver with feedback. However, the combination of both modalities can result in driver overload. Directional feedback, which provides information about the appropriate driver response, is preferred by drivers, and appears to provide at least some performance benefit. Early onset of warnings seems to have a beneficial effect on collision avoidance maneuvers, particularly for the lateral countermeasure. However the less frequent feedback from late onset warnings was subjectively preferred by the test subjects.

In probably the most striking findings of the Iowa\xl 1 simulator experiments, 31% (5 / 16) of the control subjects without road departure countermeasure support crashed when presented with a lateral disturbance (a simulated wind gust) while distracted from the drive task. In the same circumstances, only 8% (4 / 48) of the driver's with lateral countermeasure support were unable to avoid a crash. These result suggest that lateral countermeasures may indeed be effective at preventing roadway departure crashes. Unfortunately, such dramatic results were not observed in the longitudinal experiments, where none of the 64 subjects crashed due to excessive speed through curves. This was probably due to the conservative driving style of subjects in the simulator and the difficulty of creating dangerous longitudinal roadway departure situations in the simulator.

MATHEMATICAL MODELING

In order to evaluate the performance of alternative countermeasures and develop performance specifications for roadway departure collision avoidance systems, a sophisticated analytic tool, called RORSIM (Run-Off-Road SIMulator), was developed by the project team to model sequences of events that occur during these crashes. RORSIM includes all relevant system parameters, including the vehicle, roadway, driver, environment, sensors and in-vehicle countermeasures. RORSIM is an extension of a commercial vehicle modeling system called VDANL, from Systems Technology Inc.

The potential effectiveness of alternative lateral countermeasure systems was estimated using RORSIM by comparing their performance to that of an existing roadway departure countermeasure, roadside rumble strips. Like the electronic lateral countermeasures tested in this effort, the rumble strips provide feedback to the driver when the vehicle begins to drift off the road. The results of simulations with RORSIM indicate that the electronic countermeasures can significantly reduce the vehicle's maximum lane excursion during near roadway departure crashes relative to roadside rumble strips, which have already been shown to prevent up to 70% of run-of-road crashes. This enhanced effectiveness is due primarily to the ability of the electronic countermeasures to anticipate the road departure prior to the vehicle actually departing its travel lane, and therefore provide additional time for the driver to respond.

Mathematical modeling was also conducted for longitudinal countermeasures. The analysis indicates that an estimate of the distance to the upcoming curve with an accuracy of better than 40ft is necessary if the countermeasure is to provide an accurate and timely warning of excessive speed. This result implies that non-differential GPS may be adequate to warn the driver of the presence of a curve ahead, but differential GPS may be required if the countermeasure is to provide warning of excessive speed. These analyses also showed that errors in the estimate of available side friction of less than 0.15 can lead to a 10% error in the estimated safe speed for a curve. This suggests more research is necessary to determine a quick and accurate method of estimating available friction.

PRELIMINARY PERFORMANCE SPECIFICATIONS

The results of the above tests and simulations were used to generate preliminary performance specifications for potential run-off-road countermeasure systems. In order to be as comprehensive as possible, the performance specifications were generalized to be technology independent whenever feasible. Concrete values were provided for those performance specifications where the tests and analyses provide specific minimum performance criteria. A total of 60 specifications were developed, addressing sensing, processing and interface functions. A representative sample of these specifications is provided below:

Sensing Specifications:

- The system shall operate in all reasonable environmental conditions.
- The system shall be capable of operating over the range of typical road types including those wihtout lane markings, and those where the lane markings are worn or in some other way degraded.
- In the rare conditions where countermeasure performance is significantly degraded due to extreme environmental conditions, the countermeasure shall recognize the situation, discontinue operation and communicate its status to the driver.
- The system shall measure vehicle speed to within 4 fps.
- The system shall measure the vehicle's lateral position to within 0.1 ft.
- The system shall be able to function on curves as sharp as 200 ft radius.
- The system shall be able to detect when the vehicle is traveling in an unstructured environment such as a parking lot, and suppress warnings to avoid false alarms.

Processing Specifications:

- The system shall estimate the upcoming road curvature to within 10%.
- The system shall estimate the distance to an upcoming road feature, such as curve entry, to within 20ft.
- The system shall quantify the danger of lane departure and trigger a response if the danger exceeds some threshold. The danger may be measured in terms of time remaining until departure, the magnitude of the corrective maneuver required to avoid a crash, or some other measure.
- The decision algorithm shall consider the expected driver reaction time in determining when to trigger an alarm. The assumed total reaction time shall be **no** less than 1.5 s, including the time required by the countermeasure, the driver, and the vehicle.

Driver Interface Specifications:

- Warning signals shall not be so intense or complex as to overload driver.
- If possible, the system shall indicate appropriate driver response.
- If active braking is employed, it shall not impair the driver's ability to steer.
- The system shall not prohibit the driver from making safe lane changes, driving on the shoulder to avoid obstacles in the travel lane, or stopping beside the road for a vehicle or passenger emergency.

REMAINING WORK

The Phase I results are very promising: it appears effective roadway departure countermeasures are possible using existing technology. However several open questions remain, and will be addressed in Phases II and III of the program. First, the team will test improvements in the countermeasure technologies to improve their effectiveness. In particular, tests will be performed to evaluate alternative methods for sensing degraded roadway conditions, an important causal factor for roadway departure crashes not addressed in Phase I of this program. Also in the area of improved technologies, the team intends to test adaptive countermeasures, which modify their processing to accommodate variations from one driver to the next. This should reduce the frequency of false alarms, which could otherwise significantly reduce driver acceptance and system effectiveness. Evaluation of these techniques will require relatively extended tests by a number drivers.

The second focus during the remainder of the program will be on the development and application of improved techniques for estimating system effectiveness. The comparison with real data collected for roadside rumble strips performed for Phase I provided valuable insight into potential countermeasure performance, and extensions of this technique to account for more aspects of countermeasures. Finally, the results of these tests and analyses will be used to refine, quantify and validate the preliminary performance specifications developed as part of Phase I.

Data Acquisition System for Crash Avoidance Research

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INTRODUCTION

The Development of a Portable Driver Performance Data Acquisition System for Human Factors Research project is a 39 month (program inception was October, 1992) two-phase effort sponsored by the United States (U.S.) Department of Transportation (DOT), National Highway Traffic Safety Administration (NHTSA), Office of Crash Avoidance Research (OCAR), and performed by Oak Ridge National Laboratory (ORNL). The primary objective of the project is to develop a portable data acquisition system for crash avoidance research (DASCAR) that will allow driver performance data to be collected using a large variety of vehicle types and that would be capable of being installed on a given vehicle type within a relatively short time frame.

The DASCAR development process is as follows:

PHASE I, Feasibility of Developing a Portable Driver Performance Data Acquisition System (complete)

- Become familiar with NHTSA human factors research that would benefit from use of a portable data acquisition system.
- Identify parameters and measures.
- Identify the analysis tools and methods that could be used to assemble, analyze, and evaluate the data in relation to safety issues.
- Identify measurement techniques and state-of-the-art hardware to support development of an in-vehicle data acquisition system.
- Develop design requirements and specifications for a portable driver performance data acquisition system.
- Determine the cost of one or more copies of the proposed data acquisition system.
- Prepare the phase I final report.

PHASE II, Development and Test of the Prototype Data Acquisition System (in-process)

- Develop plan and construct the prototype driver performance data acquisition system.
- Prepare an evaluation plan.
- Conduct the evaluation, update the system, and perform pilot research.
- Demonstrate and deliver the system, and train NHTSA staff.

OVERVIEW

Given the diverse nature of circumstances leading to motor vehicle crashes and the associated problem areas and issues, the development of effective collision avoidance countermeasures can only be realized through a comprehensive knowledge and understanding of both the antecedent events which lead to crashes and the relative contributions of behavioral, vehicular, roadway, and environmental factors. The evolution of effective advanced technological countermeasures, however, goes hand-in-hand with the availability of a comprehensive set of research tools to investigate the causes of crashes and the influence of vehicle design characteristics on the relationships among the driver, the vehicle, the roadway, and the environment. This is particularly important where advanced technology applications may themselves increase the potential for crashes or their severity under a given set of conditions.

The availability of these research tools is vital to fully understand and document the safety benefits and potential liabilities associated with a wide range of countermeasures and technological advancements, and to define the requirements associated with their design and implementation. Such a capability must allow for a flexible, comprehensive, and valid appraisal of countermeasures and advanced technology applications.

In this regard, recent technological innovations and developments in computational speed, miniaturization, communications, and data acquisition provide the opportunity to develop a set of new and innovative evaluation tools for addressing the wide range of issues associated with existing problem areas as well as those involving the development and implementation of new advanced technological systems within the motor vehicle-highway environment. These advances have also greatly enhanced our ability to develop the sophisticated tools needed to carry out a systematic and controlled evaluation of new technologies under operational or high fidelity conditions.

The NHTSA envisions many future situations in which the effectiveness and consequences of new intelligent transportation systems technologies will need to be studied in actual production vehicles. Such studies will enable evaluations in vehicles which are familiar to drivers. These studies would be further enhanced by the availability of an instrumentation package that can be easily installed in these vehicles to enable specific vehicle configurations of interest (e.g., pedal placement, head-up displays) to be evaluated, thereby increasing the variety of vehicle options (incorporating advanced technology) that are available for study. Ideally, an approach is needed that would allow data collection from a variety of vehicle models and types, and would address the issue of driver familiarity.

Such an approach is embodied in the concept of a driver performance data acquisition system that could be installed in a wide range of vehicles within a relatively short period of time. As a universally adaptable system, it would provide researchers with the ability to manually input data as well as directly record information on driver, vehicle, roadway, and environmental parameters. Furthermore, it would enable the measurement of driver performance in the driver's own vehicle, thereby ensuring vehicle familiarity. In addition, it would be possible to measure driver performance in relation to any vehicle design characteristic at relatively little expense and effort, and would make it easy to update existing models of driver/vehicle behavior to reflect performance characteristics in vehicles of current manufacture. The availability of such information would lead to improved problem identification in crash avoidance research, as well as provide NHTSA with the capability to readily answer questions related to vehicle design characteristics not otherwise available. In addition, such a system has the potential to measure driver performance as it relates to the location of surrounding vehicles. This would allow the study of how drivers interact with other vehicles in their immediate vicinity.

DOCUMENTS PRODUCED THUS FAR

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Determine the Cost of One or More Copies of the Proposed Data Acquisition System, Draft interim letter report, USDOT/NHTSA/OCAR, March, 1994.

Development Plan and Construction of the Prototype Driver Performance Data Acquisition System, Draft prototype development plan, USDOT/NHTSA/OCAR, November, 1994.

REQUIREMENTS

The development effort for DASCAR was driven by a number of requirements which are described below.

Parameters and measures. The data acquisition system shall be capable of gathering over fifty driver, vehicle, and environment parameters and measures. Driver related variables consist of driver control actions (e.g., accelerator/throttle, brake pedal, and steering), equipment status (e.g., cellular telephone, cruise control, and hand location), and physiological measures (e.g., fidget index/gross body movement, blood pressure, and body temperature). Vehicle parameters include, for example, acceleration, headway, lane keeping, pitch, roll, and yaw. Environment considerations consist, for instance, of ambient illumination, road gradient, wind direction, and congestion, mix, and proximity of traffic.

Off-the-shelf and state-of-the-art. The DASCAR shall be comprised of both off-the-shelf hardware and software, and state-of-the-art technology. ORNL procured most of the system required equipment; some of the hardware and software had to be designed and developed.

Portabilitv. The data acquisition system shall be portable. It shall be capable of being installed on a particular vehicle within a relatively short time frame. The DASCAR shall be able to be subsequently removed and placed within another vehicle in a small amount of time.

Automobiles and trucks. The data acquisition system shall be designed so that it can be installed within virtually any passenger vehicle (i.e., a large variety of automobiles and trucks made in the U.S.). It shall be able to be mounted within vehicles of all three domestic vendors (General Motors, Ford, and Chrysler) and across a wide range of vehicle types (i.e., compact, intermediate, and large automobiles, vans, and small, mid-size and large trucks).

Unobtrusiveness and inconspicuousness. The DASCAR shall be unobtrusive to the driver. Placement of hardware within the vehicle shall not obstruct the driver's primary task of driving. Instrumentation and cables/wires connecting different pieces of the system shall be hidden, well out of the view of the driver. The data acquisition system shall also be inconspicuous to the outside world. Antennas, sensors, and cameras have be situated on the exterior of the vehicle so that they cannot be seen by other drivers. As far as possible, the vehicle shall look and drive like any other vehicle on the road.

Modularity and flexibility. The DASCAR shall be modularly designed; that is to say, the system shall permit installation of only those data collection capabilities required for a particular study. An individual shall not have to instrument the vehicle with the entire system in order to collect or record a subset of parameters. The data acquisition system shall also be designed so that it has the flexibility to accommodate new data acquisition and sensor technologies as the state-of-the-art changes.

Three modes of data collection. The DASCAR shall have three modes of data collection. The first shall consist of recording parameter data on-board the vehicle via a laptop computer. This mode shall also provide backup capability in the case of radio link failure or signal corruption during transmission. The second mode shall be comprised of radio telemetry. The radio telemetry link shall be used to transmit data from the vehicle to a base station during use at a test track. The third shall include either cellular telephone and/or satellite transmission equipment. This technology shall be employed to transmit data from a vehicle in an open road situation, somewhere in the U.S., to a base station a few to many hundreds of miles away.

Extended neriods of recording data and cost. The DASCAR shall collect parameter data over two extremes of time - from as little as 20 minutes up to 6 months. The data acquisition system shall be designed with cost as a main consideration. Technical capabilities - cost tradeoff analyses were performed for each piece of the data acquisition system.

DIAGRAMS

The DASCAR consists of five components: a data acquisition platform, a data storage and transmission system, a power supply, a sensor suite, and a video data system. A block diagram of the data acquisition system design is shown in Figure 1.

The data acquisition platform is used to capture and process signals from the various sensors installed within and around the vehicle. The data storage and transmission system is comprised of several components (i.e., cellular telephone equipment, radio telemetry, a laptop computer, dockingstation, a small computer system interface (SCSI) hard drive, and a large removable SCSI hard drive) and is utilized to receive, assemble, transmit, store, and integrate the parameter data collected via the DASCAR sensor suite. The power supply includes three items, a battery, an isolator and switching power supplies. The sensor suite is comprised of transducers, systems, devices, sensors, and meters to gather parameter data from the driver, vehicle, and environment.

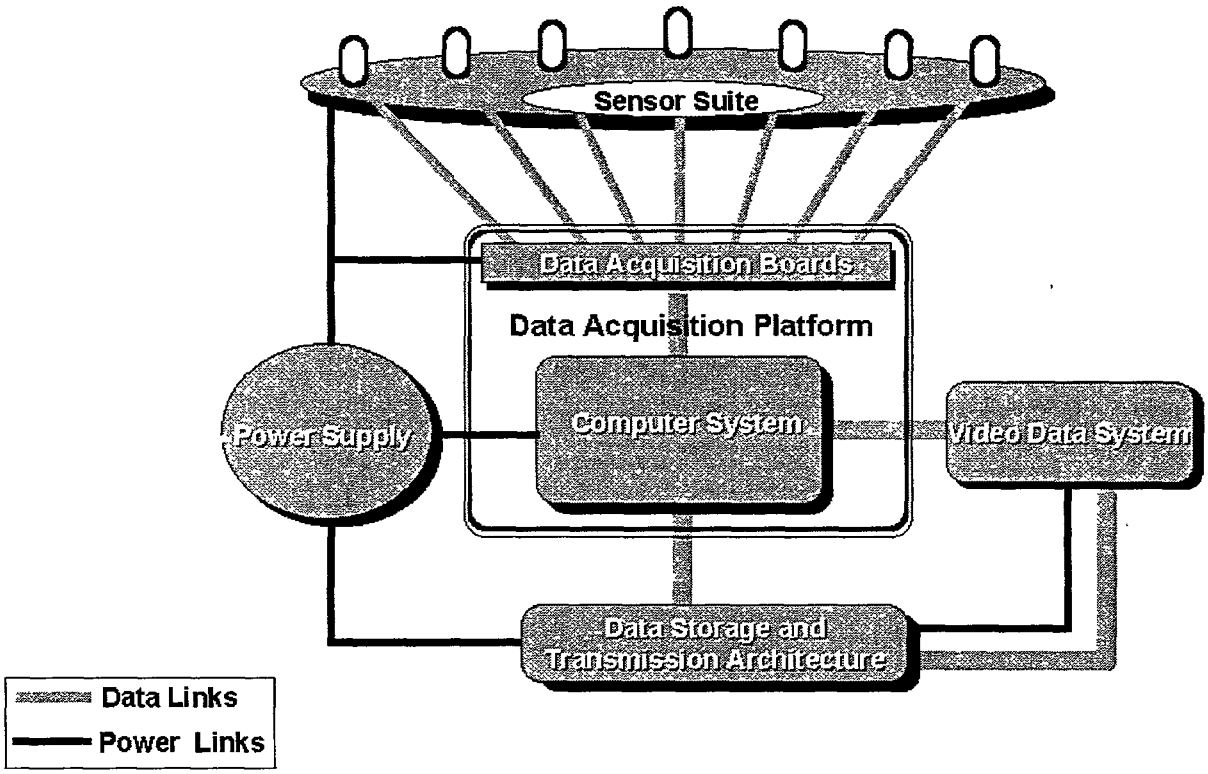


Figure 1. DASCAR Overview Block Diagram

DASCAR SENSOR SUITE

The data acquisition system sensor suite includes: linear position transducers, a pedal force transducer, a rate sensor, an ambulatory data recording system, a six degree of freedom orientation sensor, Hall effect sensors, an electronic compass, range sensors, radiometers/photometers, a sound level meter, a lane tracking system. and a global positioning system (GPS).

The linear position transducers are employed to collect steering and throttle data from the vehicle. The pedal force transducer are utilized to record brake pedal application force. The rate sensor is used to collect fidget index/gross body movement data from the vehicle driver. The ambulatory data recording system is employed to collect body temperature, electroencephalogram, electromyogram, electrooculogram, galvanic skin response, electrocardiogram, skin temperature, and respiration data from the driver. The six degree of freedom orientation sensor is utilized to record acceleration (lateral, longitudinal, and vertical), pitch, roll, and yaw data from the vehicle and road gradient data in the environment. The Hall effect sensors are used to collect fine steering, distance traveled, and velocity data from the vehicle. The electronic compass is employed to record heading data from the vehicle. The range sensor is utilized to collect headway and tailway data from the vehicle. The radiometers/photometers are used to record ambient illumination and glare data from the environment outside the vehicle. The sound level meter is employed to collect steady state and impulse noise as heard by the driver inside the vehicle. The lane tracking system is used to collect lane keeping data from the vehicle. The GPS receiver is used to collect vehicle location and route traveled.

DASCAR VIDEO DATA SYSTEM

The DASCAR video data system is comprised of both color and black-and-white video microcameras, a time code generator, a digital quad picture processor, a digital picture transmission system, and a super VHS recorder. The microcameras are utilized to record video data inside the vehicle and in the outside environment, and consist of camera heads, lenses, control units, and cables. The time code generator is employed to provide video data synchronization with collected data. The quad picture processor is used to display and record images from four video microcameras at one time. The digital picture transmission system is utilized to send high quality color pictures to the central data collection/analysis facility in near real time.

DASCAR CENTRAL DATA COLLECTION/ANALYSIS FACILITY

A central data collection/analysis facility has also been assembled to manage all of the parameter and video data. The facility is based around a personal computer platform. Support systems include: an MPEG encoder/decoder digital video system, a quad picture processor, a super-VHS recorder, a super-VHS monitor, and a digital picture receiver system. Collection of the DASCAR parameter data at the central data collection/analysis facility is handled in several ways: data will be transferred via removable SCSI hard disk; data will be received through radio telemetry equipment; and/or it will be received through cellular/land lines. Video data will be transferred via analog tape(s) and then digitized onto hard disk for storage and analysis. The digital picture transmission system is used to transmit still video images from the system in the field (compressed digital video has too large of bandwidth to transmit full motion video from a moving vehicle with current communication technologies.)

DATA MANAGEMENT PLATFORM:

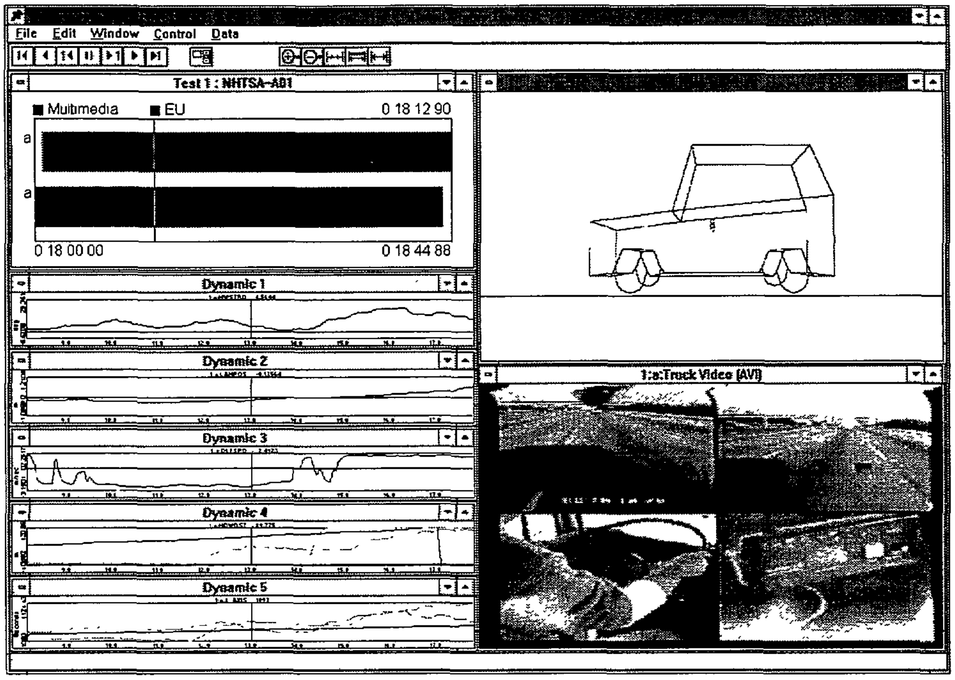
Given the range of data collection scenarios and parameters available in DASCAR, addressing data reduction, analysis, access and archiving requirements represents a major challenge in system development. In addition to the large quantity of non-video data, there would be an enormous quatity of video data that would have to be time synchronized to the other data. Access to such data would require a multimedia data management platform that would allow integration of vast amounts of diverse data formats (e.g., analog, digital, event data) and time histories (e.g., various sample rates). The framework for such a platform was available within an existing DOD program involving the Air Force and Calspan Corporation. Under contract to the Air Force Armstrong Laboratory, Calspan developed an integrated set of commercial off-the-shelp and custom software to support the analysis of aircraft flight test data including the capability to integrate video and animation models. A version of this system, called Test PAES (Test Planning, Analysis and Evaluation System) is currently being converted from an aircraft oriented framework to one that will support analysis of ground transportation systems. The system includes database, guidance and multimedia analysis tools that enhances data handling in five ways: 1) providing guidance on what data are most likely to be sensitive to the factors being evaluated for quick-look analysis, 2) providing automatic time synchronized data from various data sources to support cross correlations, 3) supporting interactive, multimedia data analysis enabling the user to view data in a vast array of formats, 4) exporting user-selected data to standard spreadsheet and statistical packages, and 5) entering and retrieving archival data.

Insofar as the integrated system can support a wide range of research needs, from planning to reporting and archiving, it is viewed as an opportunity to achieve some level of uniformity in data collection across researchers. Such uniformity facilitates the sharing of data and allows for more meaningful comparisons of results. Table 1 summarizes the basic Test PAES capabilities while Figure 2 illustrates a sample Test PAES data display tool.

Table 1 Test PAES Capabilities

Capability	Description
Process Support	This capability provides guidance in performing the Structured Test and Evaluation Process (STEP). A graphical representation of the STEP is presented along with appropriate tools, documents, and forms to assist the Test PAES user in performing and tracking progress throughout system testing and evaluation.
Database Access	This capability provides access to the Test PAES databases throughout the STEP. The available databases are: Dictionary, Lessons Learned, Measures, Card Catalog, Note Pad, Structured Test Procedures, Event Log, and Time Sampled Data.
Multimedia Data Analysis Playback	This capability provides playback of video, audio, and engineenng unit (EU) data simultaneously in resizeable windows. The playback is controlled using VCR like controls with forward and reverse play at selectable speeds.
Multimedia Authoring	This capability provides the hardware and software necessary to digitize video and audio data into various Windows media formats (such as Audio Video Interleave (AVI) file format). Because digital video is storage intensive, the hardware necessary is dependent on individual site requirements.
Integrated Commercial Peripheral and Application Support	This capability provides compatibility with commercial hardware peripherals and software applications that are useful in performing the STEP. These hardware and software items are optional and should be evaluated individually to determine if their capability is necessary.

Figure 2. Data Display Tools



DASCAR SPECIFICATIONS

<u>Data Acquisition Platform</u>

Processor	Motorola MC68331 microcontroller
Memory	2 Mb Flash 1 Mb Fast Static RAM
Max Sample Rate	8 KHz (aggregate) ; 4 KHz (w/ laptop)
DAP Interfaces	
- single ended	48
- differential	48
- synchro	3
- pulsed	8
- discrete outputs	8
- serial ports	5 (1 dedicated to internal diagnostics)
DAP additional interfaces w/ laptop	
- parallel ports	1
- serial ports	9 (1 built in ; 8 from expansion card)
- PCMCIA slots	4 type II or 2 type III

Driver Parameters

Driver Control Actions

	Sensor	**Range**
Accelerator/throttle	TPS from Vehicle	dc to full scale
Brake pedal	Brake Pedal Force Transducer	0.4 to 136 Kg
Steering wheel	Linear Pot and/or Hall Effect	TBD

Equipment Status

Brake lights	On/Off
Hazard flasher	On/Off
Headlights	On/Off
Horn	On/Off
Parking lights	On/Off
Rear window defogger	On/Off
Seat belt	On/Off
Turn signals	On/Off
Windshield wipers	On/Off
Rear window wipers	On/Off
Auxiliary Device (e.g. side object detect)	On/Off
Auxiliary Device	On/Off

Physiological

	Fixed Rate	**A/D resolution**	**Range**
Electroencephalogram (EEG)	50 Hz	8 bit	1 - 25 Hz
Electrocardiogram (ECG)	50 Hz	8 bit	1 to 25 Hz
Electromyogram (EMG)	10 Hz	8 bit	20 - 500 Hz
Electrooculogram (EOG)	10 Hz	8 bit	.08 - 5 Hz
Galvanic skin response (GSR)	10 Hz	12 bit	0 - 50 μΩ
Respiration	10 Hz	8 bit	n/a
Skin temperature	1 Hz	12 bit	0-500¡K
Core temperature	1 Hz	12 bit	0-500¡K
Gross body activity (Fidget)	TBD	16 bit	TBD

Vehicle Parameters

	Sensor	Full Scale
Acceleration	Motion PAK	
- Lateral		-2 g to 2 g
- Longitudinal		-2 g to 2 g
- Vertical		-2 g to 2 g
Angular Rates	Motion PAK	
- Pitch		± 100¡ / sec
- Roll		± 100¡ / sec
- Yaw		± 200¡ / sec
Headway/Tailway	Controlaser 100	
- Headway		0 to 100 m
- Tailway		0 to 50 m
- relative velocity		TBD
- time-to-collision		.1 to 4 seconds
Lane keeping	Williamson system	
- Lateral lane		0 to 1.8 m
Heading	Compass Engine	0¡ to 359.9¡
Vehicle Location	Magellan GPS	N/A
Pulsed Magnet Sens.	Hall effect sensor	
- Velocity		0 to 200 Kmh
- Distance traveled		n/a

Environment Parameters

	sensor	Full Scale
Illumination	IL-1600 A	n/a
Lumination	IL-1600 A	n/a
Noise	Quest 7000	30-140 dB

Video Derived Parameters

Car lights	Exits
Distracting lights, obstacles, and signs	Intersections
Haze/dust	One or two-way traffic
Parked cars	Pedestrians
Precipitation	Road conditions
Road lighting	Road types
Surrounding field of view	Which lane you are in
Traffic conditions	Head movements
Visibility/sight distance	Which lane you are in
Traffic lights	Traffic events

NOTES

This document was specifically written for the Peer Review of the NHTSA Program Workshop sponsored by ITS America, Advanced Vehicle Control Systems Committee. It provides contract overview as well as insight into the prototype data acquisition system that has been developed. Additional information will be presented and DASCAR will be demonstrated at the Peer Review Workshop. For further information please contact Richard Carter at:

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Status of a Measurement and Processing System for Characterizing the Vehicle Motion Environment (VME)

Robert D. Ervin and Charles C. MacAdam, UMTRI
Kent Gilbert, ERIM

One of NHTSA's research tools for building the knowledge base on crash avoidance is a measurement and processing system that can quantify how vehicles are actually being driven in normal road usage. The tool is to produce empirical data characterizing the trajectories and instantaneous speeds of individual vehicles in the midst of all other nearby vehicles, in everyday traffic. We have termed this micro-traffic context, "the Vehicle Motion Environment", or VME. Such a data set is needed for studying the performance of crash countermeasures that sense and act upon the presence of nearby vehicles or road edges. Studies of this type would support the engineering development of products, the evaluation of system concepts, and an orderly advancement of benefits assessment, specifications, and standards for crash avoidance systems.

Under a Cooperative Agreement, NHTSA has been supporting a joint effort by the University of Michigan Transportation Research Institute (UMTRI) and The Environmental Research Institute of Michigan (ERIM) to develop and demonstrate a "Measurement and Processing System for Quantitatively Characterizing the Vehicle Motion Environment". A complete ensemble of hardware and software subsystems has been built and subjected to initial trials and an effort to further refine the system technology is now proceeding. When fully operational, the portable measurement system would be moved from one road site to the next around the country, compiling an archival data set that would represent the near-range behavior of vehicles operating in traffic in the U.S. In this context, a national archive of VME data is seen as analogous to the archive of accident data. That is, just as we have used the accident record to document our national crash experience and, in turn, to help in developing "passive safety technology", so the VME data record would document our national everyday-driving experience in terms that would assist in developing an "active safety technology" (AST).

An engineering characterization of the VME will require that real roads and traffic motions be measured for a period of a month or so at each of many selected road sites. Altogether, the measurements must cover a representative sample of sites covering geographic, climatic, road design, illumination, traffic characteristics, and other factors. At a given road site, each motion and space variable must be quantified from one instant in time to the next so that, eventually, data are collected providing statistical distributions of these variables representing the vehicle operations within which crash-avoidance products would be deployed. Thus VME data would constitute an engineering tool for understanding and predicting the in-field performance of AST systems. Altogether, such an archive would constitute a massive data resource and would require a sustained commitment for its acquisition and maintenance not unlike the commitment that has attended the compilation of the computerized accident record.

This paper will briefly characterize the state of VME development and review the plan for its application. At the end we also review the broad rationale for VME measurement in the context of the global initiative to advance crash avoidance technology.

A System for VME Measurement

The Vehicle Motion Environment Measurement System (VME-MS) currently constitutes three complete sensor stations, each of which is as shown in Figure 1. The hardware at each station comprises a 100-foot telescoping tower, a utility trailer platform, and a package of electronics supporting the sensing and raw-processing operations. The electronics unit is shown in Figure 2, containing packages that control the enclosure’s temperature and support the on-board processing functions. A complete system for managing lightning strikes on the tower is included within the enclosure. The intent is that the electronics unit can operate unattended for at least 24 hours at a time, compiling data for later recovery via magnetic tape.

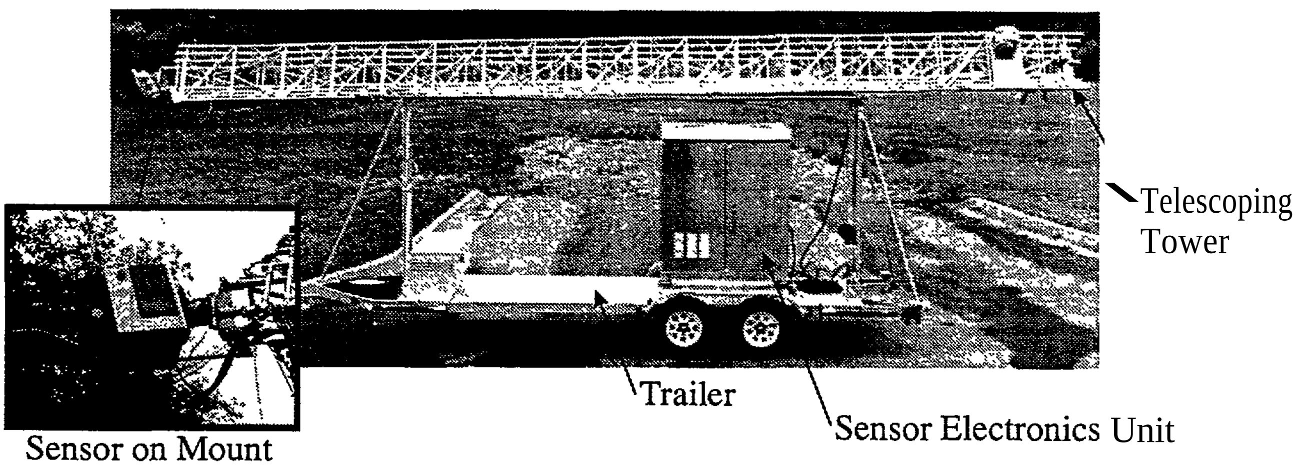


Figure 1 VME-MS Sensor Station Equipment

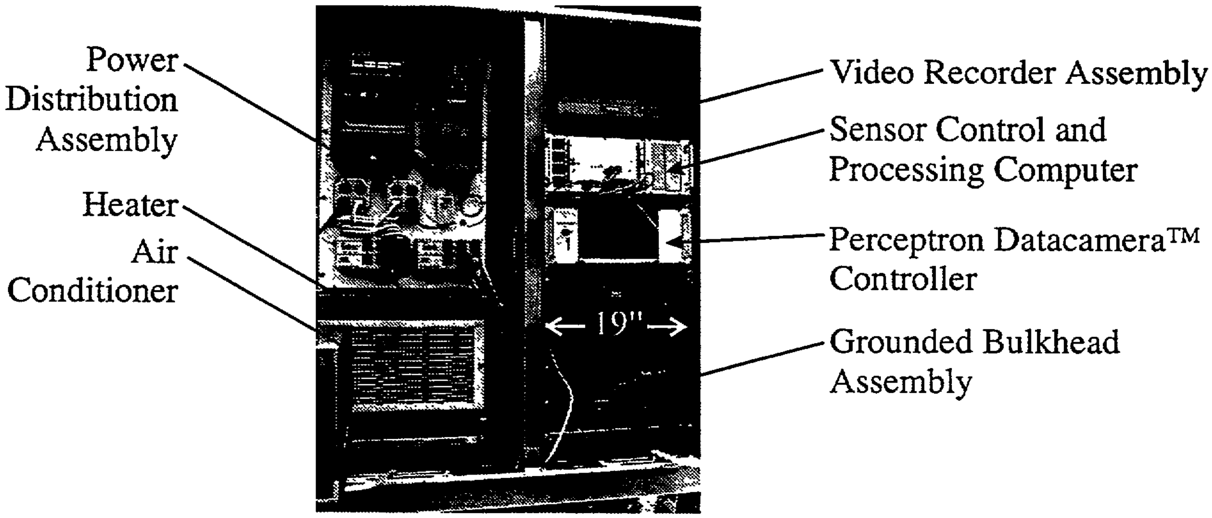


Figure 2 VME-MS Electronics Enclosure

Figure 3 illustrates an installation of the ensemble of three sensor stations along a straight portion of roadway with an ethernet connection link joining the two free-standing sensor electronics units to the "master" electronics unit. The master unit establishes the correspondence of vehicular images seen by one sensor to those seen on the same vehicle by the next sensor, eventually piecing together a continuous file which tracks each passing vehicle throughout the entire observation zone. Each sensor station can track up to 32 vehicles at a time over a 60' x 200' section of roadway. Adjacent sensor stations can be arranged in any mosaic pattern of overlapping (60 by 200 feet) rectangles. The features of the VME-MS system are summarized in Table 1.

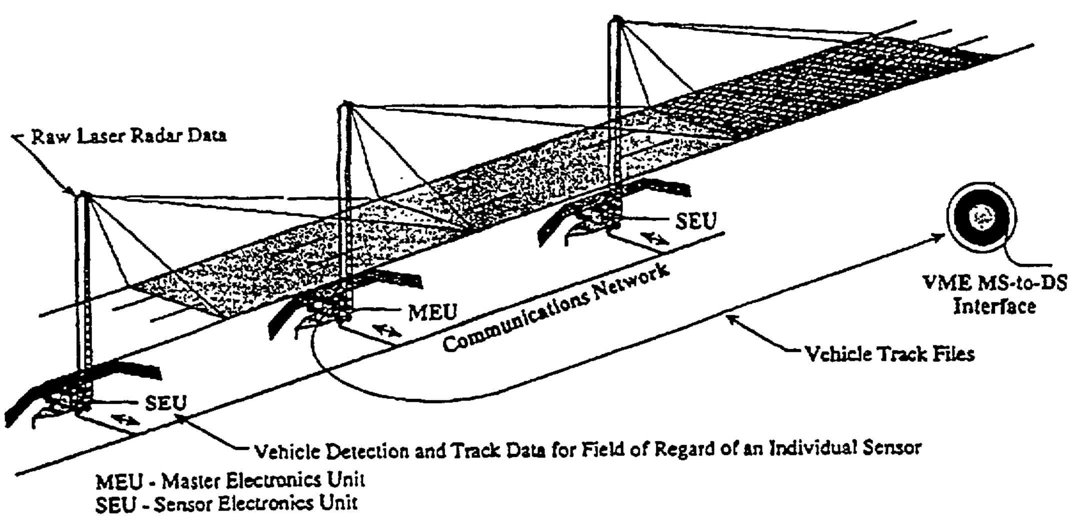


Figure 3 Layout of Three Sensor Stations Along a Straight Roadway

Table 1 Features of the VME-MS

Coverage Area per Sensor Station	60’ wide x 200’ long
Number of Sensor Stations	3
Deployment	Along roadway, around intersections, at freeway on/off/merge lanes, etc.
Output Data	Real-time generation of vehicle track files for up to 32 vehicles per sensor station
Data Rate	10 frames/second,
Data Accuracy	1) X-Y track of vehicle centroid ~ +6” 2) Vehicle length and width ~+3” 2) Yaw angle + 2u @ 120 ft. slant range Yaw angle + 8u @ 300 ft. slant range
Coordinate System	Established in the Roadway Surface
Roadside Platform	Utility Trailer with 100 Ft telescoping tower Self-contained sensor station electronics + ethernet Full lightning protection and environmental control
Tracking Sensor	First Phase Effort: Laser-based range- imaging sensor Second Phase: Digital CCD camera
Video Record Sensor	Conventional analog surveillance camera & VCR
Data Processor	Commercial single-board computers
Output Records	1) Track file & incident flags 2) analog CCD camera for video archive
Recording Media	1) Digital Audio tape for vehicle track files 2) Video cassette for video imagery
Times of Operation	Daytime or high level, artificially-illuminated nightime

The “Tracking Sensor” produces the raw imaging data from which vehicles are located, measured, and tracked every tenth of a second throughout their presence in the scene. In the first phase of the VME project, a laser-based range-imaging sensor has been assembled and studied for this application. In a second phase of the effort, a digital CCD (charge-coupled detector) device will be examined as the Tracking Sensor. (The state of the sensor selection will be discussed below.) Co-located with the Tracking Sensor, at the top of the tower, is also a conventional analog CCD camera providing temporally synchronized backup video to support “manual” review of selected segments of the data.

The output of the VME-MS is a high-level result comprising a stream of so-called, “track files”. The track file is defined as a 10-Hz sample of the X-Y location coordinates of the geometric centroid of one particular vehicle passing through the scene, and its instantaneous yaw angle The track file "picks up" each vehicle as it enters the observation zone across one of its boundaries and "tracks" it until the vehicle exits across a zone boundary. In the header of each track file, the length and width of the vehicle is captured and ancillary data are included that will facilitate later processing. Since track files all have a common time base, later processing of these data can determine the inter-vehicular relationships which prevailed during the measurement, thereby enabling a host of analyses that may address crash avoidance phenomena.

Experience with a Laser Sensor in Phase I

In the initial stage of the VME project, the hardware and software elements for this measurement system were built and exercised in an actual roadside environment in Ann Arbor, Michigan. Based upon the overall experience of implementing and exercising this package, it is clear that the initial technology selected for sensingNnamely, that of laser-based range imagingNis insufficiently mature at present to support the VME program as envisioned by NHTSA. In a macro sense, it appears that the state of the *industrial art* is well behind that of the raw *technological art* of laser range-imaging that has been demonstrated in scientific laboratories and has been built for certain costly military applications. The absence of a commercial market for the high-power (l-watt, average) and high bandwidth (10 Hz sampling) laser sensor is obviously responsible for the limited industrial capability in this area. This state of affairs has impacted upon the overall VME program insofar as the prototype laser-sensor units were unable to meet the specifications for the VME application and indeed, were unable to produce even crude samples of an ouput track file.

Notwithstanding the unsuitability of laser sensing for the VME measurement system, the remainder of the VME hardware and software assembly has been shown to be fully operable through the recent field installation activity. Various features of both the measurement and processing ends of this system have been successfully exercised by operating on simulated data.

At this juncture, the parallel choice of digital CCD sensing is being pursued. Clearly this approach trades off the hardware sophistication of the laser sensor for the software sophistication of video image processing where each pixel represents a brightness level rather than a range-to-object value. On the other hand, the enormous rise in commercial markets for video image applications serves the VME program by offering rapidly advancing hardware and software products, at declining prices. The task of adapting video sensing to the existing VME measurement system will be discussed at the Workshop and clips of recorded images will be shown to illustrate the level of data quality that can be anticipated.

Processing of VME Track File Data

A "Data System" (the VME-DS) for processing VME results has been developed in parallel with the advancement of the measurement system. The VME-DS package has been designed to permit a wide array of analyses of track-file data. The features of this package have been selected based upon an imagined set of interests in VME data analysis as characterized below:

At perhaps the simplest level, one can imagine the direct processing of track file data, one vehicle at a time, in order to generate histograms of lateral and longitudinal acceleration, speeds, position in lane, and the like. Contemporary track files from nearby vehicle pairs can also be processed to derive the intervehicular-closure vectors by which two vehicles approach one another, the angles of attack relative to vehicle centerlines or ground-fixed coordinates, the instantaneous clearances, headway times, etc., as a function of time or spatial variables. One common inquiry may involve the search for traffic-conflict-type events, or incidents, based upon a running computation using track file variables. For example, an algorithm might scan all values of time-to-collision (TTC) as a means of detecting cases of near missesNeventually extrapolating to the collision potential that may be implied. The processing system can then report back every case falling below some threshold value of TTCNperhaps in conjunction with the vehicle's absolute speed.

Other users may wish to quantify variables not present in the raw track files, as they are directly measured in the field. Variables such as vehicle yaw rate, body sideslip angles, and front wheel steer angle might have special utility for studying specific crash-avoidance issues. The VME-DS has been configured to generate a variety of such "supplemental variables" by means of a relatively common signal processing scheme known as Kalman filtering. The Kalman filter employs a simplified internal model of the vehicle (scaled according to the measured length and width parameters) in combination with the track file data to obtain a best estimate of the system behavior from measurement to measurement. The model estimates can readily include other continuous variables describing the vehicle and, implicitly, the control inputs applied by the driver. When specific vehicles are to be modelled with more precision such as in reconstructing a crash or near-miss event, examination of footage from the accompanying video camera may help in further identifying make and model of the vehicle in question so as to refine the Kalman filter's internal model.

At perhaps the highest level of VME data application, one could simulate the operation of a concept crash-avoidance package, using a combination of VME variables as the truth environment. For example, a road departure warning system being developed in the future may require on-board signals representing steering wheel angle, forward speed, and yaw rate as well as sensory signals showing vehicle position and heading angle relative to the upcoming lane edge. The VME data file could support a simulation of this system by generating a continuous data set containing each of these variables for each "host vehicle" that was observed by the VME roadside measurement package. Occlusion of this system's view of the lane edge by vehicles just ahead of the host vehicle could also be represented in this example by computing the orientation of sensing shadows cast by the preceding vehicles, using the contemporaneous track files. A running computation of the response of the simulated warning system, on many thousands of vehicles passing through various sites, would render a clinical, repeatable, assessment of the system's performance as it is influenced by normal pathkeeping activity, geometric variables, and motions of the host vehicle relative to others nearby. Where anomalies in the response of the simulated system are observed, the cases in question can be flagged for more detailed followup analysis.

Accordingly, it is clear that a variety of post-processing programs and algorithms are likely to have value, each tailored to specific types of application. The VME-DS software package has been developed to enable all of the applications cited here for processing VME track files. It provides each of these features within a structured data management environment, permitting efficient analysis of very large quantitites of field data.

The Role of VME Measurement in Advancing the Science of Crash Avoidance

Without VME data of the type described here, it is felt that the process of refining collision warning and intervention systems will be overwhelmingly empirical in nature and thus quite handicapped as an engineering endeavor. The empiricism will derive from the simple fact that the pre-crash environment remains virtually unquantified, as it prevails throughout the nation. Thus, the only way one can tell if a given sensor/processor package is any good, under the current state of affairs, is to take it out on the road and try it. But wherever one tries it, the inter-vehicular motions prevailing at the time of testing will be unknown and unrepeatable in any controlled senseNthus making it difficult to relate the package's performance to the condition variables. Given that the driving process has both random and methodical (situation-based) components, attempts to simulate this application environment will be largely speculative until some robust form of "truth data" is brought forward through a direct-measurement characterization. The basic problem is that we have essentially no information that is both quantitatively and statistically representative of the longitudinal and lateral clearances between vehicles, the angles of approach, or the time derivatives, thereof. Neither can we describe the correspondences (i.e., control relationships) between these inter-vehicular variables and the steering and braking actions which the broad population of drivers actually take, each responding to his or her immediate "motion environment". This is a sobering state of affairs. We are without definitive data on an exceedingly complex application environment toward which a large industry around the world is now targeting an array of new (crash avoidance) technology, seeking to improve a process that fundamentally effects the life and health of a billion or more people, everyday.

The extent of the need for VME data can be seen upon consideration of the challenge faced in developing AST products. The central observation, confirmed now by some industry engineers who have begun to work on active safety packages, is that the detection of full-blown, fast-closing collision threats is not too difficult if the system waits long enough to make a decision. But then, the time-to-respond may be intolerably short. Many sensing technologies, even with crude processing algorithms, can tell a bona-fide crash-in-the-making when it is well developed and more or less inevitable. The hard part is to create sensor/processor systems that can discern the "probably-harmless" inter-vehicular actions from the "very-likely-harmful" events early in the time sequence. Clearly, since candidates for crash-interaction develop around each motor vehicle hour after hour, throughout the driving process, the opportunities for false alarm are pretty much unbounded. Any suitable active safety technology must accomplish the remarkably complex task of accepting the many thousands of episodes which are, indeed, benign while not ending up in such a mathematical stupor that the bona-fide collision threat is missed or its detection is delayed beyond the minimal time window needed for safe intervention. On the assumption that frequent false alarms and, worse yet, false control interventions, will render active safety products unusable, the achievement of high levels of "active safety intelligence" seems a requirement. But the engineering of such intelligence into these products appears, in turn, to require an accurate targeting of the technology to the complex motion environment as it really prevails. Such a task, in turn, requires that this "target" be representatively characterized.

However the automotive industry may use such quantitative data for product planning and development, government may be disposed to employ the VME data for such purposes as identifying opportunities for crash avoidance countermeasures, preliminarily estimating the benefits of AST concepts, and evaluating specific system designs by subjecting them to statistically-meaningful sequences of VME data. A "standard" evaluation sequence might emerge by which industrial developers of technology can communicate with government regulators, and vice versa, perhaps eventually even using a VME data sequence to develop product standards covering certain "macro" aspects of safety performance.

Section III: Breakout Group Session Summary Reports

Breakout Group Sessions. Attendees were provided advanced materials on these programs, received in-progress briefings from NHTSA contractors, and formed breakout groups for in-depth discussions of the following topics:

- Rear-end collision avoidance using ITS countermeasures.
- Lane change and merge collision avoidance using ITS countermeasures.
- Run-off-road collision avoidance using ITS countermeasures.
- Applications of DASCAR and VME collision avoidance research tools.

The breakout groups were asked to respond to the following four questions in the context of each of the three collision avoidance system specifications:

(a) Are the performance specifications on the “right track?” If not, what are the suggestions for a different approach?
(b) What experiences or lessons learned can be offered for incorporation into the NHTSA program?,
(c) Will the eventual results from the NHTSA work be useful to system designers? If not, what would be useful?, and
(d) What guidance can be provided on methodologies to estimate the benefits which would accrue to systems designed to meet the performance specifications?

Group facilitators and session recorders were assigned to each group in order to focus the discussions and document the proceedings. The table below lists the breakout group facilitators and recorders; each group sequentially reviewed the three types of collision avoidance system.

Group Facilitator	Steve S hladover	Mike Martin	Mark Freedman
Monday afternoon	Lane change/merge Joe Koziol	Road-departure Duane S toltzfus	Rear-end Jim Britell
Tuesday: early morning	Road-departure Wassim Najm	Rear-end Jeff Woods	Lane change/merge Al Chande’
Tuesday: Late morning	Rear-end Mark Mironer	Lane change/merge Jack Ference	Road-departure Elizabeth Mazzae

The breakout session leaders provided a summary of the findings from each of the sessions. These summaries, dealing with run-off-the road collisions, rear-end collisions, and lane change and merge collisions, are presented below for each of the three breakout session groups. Summary reports are presented in the following order: Group 1- Steve Shladover, Group 2- Mike Martin, and Group 3- Mark Freedman.

GROUP 1: Run-Off-The-Road Collision Avoidance

QUESTION: *Are Performance Specifications on the Right Track? If Not. What are the Suggestions for a Different Approach?*

Dr. Shladover: The first question put before us was "Is this on the right track?" The answer, in general, is yes. It looks like the performance specifications are on the right track. The work appears to be going in appropriate directions. We have a number of recommendations for how the work could be improved, as well as specific modifications for some of the recommendations.

Technology Limitations

First of all, the technology limitations should be explicitly acknowledged. There are significant technology limitations in dealing with this type of crash, and we need to make sure that we are consciously aware of them, and that we are not just dealing with that implicitly. This was a nearly unanimous recommendation.

False Alarms

Second, we must examine the trade-offs between false positives and misses. It is really important to not fail to identify a genuine road departure, but we also don't want to have so many indications of run-off-the-roads that aren't really run-off-the-roads that drivers will be unhappy with the system.

Levels of Performance

There was considerable interest in defining multiple levels of performance. We recognize that an ideal system is not within our technological reach at this point. This leads to the question of establishing a minimum acceptable level of performance. While we weren't able to answer the question now, it is an important issue that a specification will need to address. Work must be done to identify how we come up with such a minimum level of performance. This level of performance includes not just performance of the system, but the kind of road and driving conditions the system will operate under effectively. A system is not likely to operate under all possible road conditions and all possible driving conditions. At what point does the system pass the threshold of being acceptable and attractive to people?

Status Information

We had an interesting discussion comparing those systems which produce alarms and those which function as more of a driver aid, providing continuous information on vehicle status relative to the roadway. While alarms or warnings may be necessary, the usefulness of augmenting alarms with more continuous information about where the vehicle is in tracking the lane or tracking the roadway was discussed.

System Limits

One very specific recommendation refers to the limits of lateral acceleration used, especially for vehicles on curves. The contractor team may wish to reduce some of the limits considered in their earlier work. These limits were based entirely on the physical limits of the vehicle going around the curve under ideal conditions and did not consider the driver's limited ability to do aggressive curve tracking.

QUESTION: *Will the Eventual Results from the NHTSA Work be Useful to Svstem Desianers? If Not, What Would be Useful?*

Dr. Shladover: The use of specifications for protection from liability was highlighted. If a manufacturer delivers a system which meets a specification, they may be provided with some degree of protection. When a crash does occur, the level of that protection is not clear. Measures of effectiveness that are objectively measurable need to be defined.

Reliability

There is interest in having the specification deal with reliability. There are several dimensions of reliability including: detection probability (i.e. the likelihood of detecting an adverse event), the minimum operating conditions for the system, and methods of providing the driver with an indication of the status of the system when the system is in a condition that it cannot work correctly (such that it cannot give useful running-off-the-road information).

Driver Training

There was a question raised about what level of driver education **or** training might be needed to operate such a system, but we did not answer it. The features of the system should have some level of standardization.

Ensuring Compliance

A test procedure should be developed to describe how a system would be tested to verify that it met the requirements of the specification. The specification by itself without that test procedure would not be nearly as useful.

QUESTION: *What Experiences or Lessons Learned can be Offered for Incorporation into the NHTSA Program?*

Mapping

Dr. Shladover: One aspect of this was to deal with the overspeed going around curves, and that was based on an assumption of digital map data to represent the curve radius. One of the points that came up is it may be either difficult or impossible to get that type of digital map data, even if there is a navigation system on the vehicle. The navigation system may not have that fidelity of curve information, and we need to talk with mapping companies to establish just how much of an issue that is.

Testing System Limits

One concern raised from other experience is that some drivers may choose to push the system to the limits. An example cited was the teenagers who drive in the red zone just to show how skilled they are, to show that they can go around that curve even when they are getting a warning.

Degraded Road Markings

Another lesson that came up was the necessarily imperfect road edge markings, and there are apparently some fairly recent data collected at University of Michigan about the condition of the road edge markings in Michigan which would be useful to reference to make sure that we are not assuming that road edge markings are in better shape than they really are.

QUESTION: *What Guidance can be Provided on Methodologies to Estimate the Benefits Which Would Accrue to Systems Designed to Meet the Performance Specifications?*

Dr. Shladover: I think the group agreed that establishing the benefits was probably the hardest issue to deal with. How do we establish what the benefits are going to be of such a road departure warning system? This is not easy to measure in advance of the existence of the system.

Defining System Capabilities

To begin with the group thought that we needed a clearer definition of what the system would be doing and until we had a really clear definition of what the system would do it is going to be really hard to estimate the benefits.

Comparison Systems & Measures

One idea was an extension of what the CMU group was already doing in comparing the in-vehicle systems to the roadside measures, and they had the example of the roadside rumble strip. The data on rumble strips are not very good at this point, but this is something that looked like it was worth continuing. Another issue that was thought to be useful for evaluating benefits was establishing some conflict severity measures to use to compare the equipped vehicles with the unequipped vehicles. The question is what variables ought to be used as those measures of effectiveness or measures of conflict severity, and how would one collect the data to be able to evaluate the system so that we could compare equipped and unequipped vehicles and try to anticipate what curve departures or road departures might have been prevented by the existence of this countermeasure that would otherwise have occurred if the countermeasure were not on the vehicle.

GROUP 1: Rear-End Collision Avoidance

QUESTION: *Are Performance Specifications on the Right Track? If Not, What are the Suaaestions for a Different Approach?*

Dr. Shladover Our group dealt with rear-end countermeasures as the last topic. Consequently, this was the last group that the Frontier team addressed. They started out by telling us what they had heard from the other breakout groups.

Continuous status Information

As with the previous collision avoidance systems, there was some interest in having a combination of continuous status indication and warning of imminent crash occurrence. It was pointed out that an imminent crash is a very rare event Thus, if the driver is not accustomed to receiving information from the system on a continuing basis, he may not know what to do when he gets that imminent crash warning.

Measures of Effectiveness

There was interest in having Measures of Effectiveness (MOE's) include both the avoidance of crashes and the avoidance of nuisance alarms. Without avoiding those nuisance alarms, drivers may choose to not use the system. There was also interest in having the algorithms defined in the specification. We all recognized we are going to have problems coming up with specific numbers to go in the algorithms at this stage, but the form of those algorithms need to be defined first. These should include the distance to the target, as well as the closing rate to the target. It couldn't just be the distance.

Degraded Operating Conditions

Specifications also need to address the performance degradation that would occur under various conditions. It is not enough to talk about how it would work under ideal conditions, but we need to consider adverse weather and road conditions, as well.

Performance/ Benefit Relationship

Some of the items that the contractor team informed us came up in the previous groups included: the need to show the relationship between the technical performance of the system (the sensor systems, for example), and the effectiveness in avoiding crashes. This relationship has to be made very explicit so that people can look at that trade-off and try to define where along that trade-off frontier a system ought to be designed.

Minimum Guidelines

There is also a need for minimum performance and guidelines, particularly from the regulatory point of view. If rear-end collision avoidance systems are adjustable, there still has to be a minimum regulated requirement of performance.

Adjustability

There was also concern that the drivers be able to turn the system off, and have some adjustability to meet their individual driving styles. Just how much adjustability should be provided in unclear.

Supporting Rationale

It is necessary for the specification work to include supporting data and rationales so that people reading the documentation can identify where the numbers originated from, since they wouldn't just take them at face value.

Performance Specifications

Specifications should define performance, not design. There was some concern that the specifications may be getting a little bit too close to design.

System Limitations

Specifications also need to define what the system cannot do, so that the limitations of the rear-end collision avoidance system are made quite explicit. They should specify the applicable road environments and not get into things like sensor field of view. Rather, specifications should just indicate the kind of road geometry, the kind of road environments in which the system ought to be working. They should also define the factors that would reduce the effectiveness of the system so that those can be taken into consideration by designers and users.

QUESTION: *Will the Eventual Results from the NHTSA Work be Useful to System Designers? If Not, What Would be Useful?*

Underlying A ssumptions Leading to a Specification

Operating Conditions

Dr. Shladover: In terms of the usefulness of the results, we came back to the need for documentation of the assumptions that go into the specification development. The background data and the reasoning that is applied in order to interpret that data leading to a recommended specification need to be explicitly stated. Without either of these, it will be very hard for people to use the document, and again, it would be unlikely for people to take it at face value. They need to see the logical sequence that gets us to a specification.

There is a need to define the relevant targets; the kind of objects and vehicles, as well as the applicable driving environments (road geometry, weather conditions, road surface conditions, etc) in which the system is designed to operate. It was felt that this needed to be defined quite explicitly. Questions also arose about what kind of information we can assume the system would have available to deal with those different conditions.

QUESTION: *What Guidance can be Provided on Methodologies to Estimate the Benefits Which Would Accrue to Svstems Designed to Meet the Performance Specifications?*

System Usage Data

Dr. Shladover: Benefits estimation was once again a really difficult issue. I think there was agreement that the relevant measure of effectiveness is avoided crashes, but in order to get at that we have to have an indication of how likely people will be to use the system. If people don't like the system and choose to turn it off, it is not going to help them avoid crashes. The difficulty is how to estimate this prospectively, before the systems are out in widespread use.

System Interactions and Disbenefits

We also had concern about interactions with the other systems. We cannot be looking at these separate countermeasures in isolation from each other. We have to look at them as they would be applied together, and how the driver would use them as an integrated system. Modeling needs to be done to address this, but there is a question about what kind of assumptions ought to be built into those models in order to produce realistic estimates of the benefits. We have to consider the potential disbenefits that might be occurring inadvertently, as well.

QUESTION: *What Experiences or Lessons Learned can be Offered for Incorporation into the NHTSA Program?*

Stakeholder Involvement

Dr. Shladover: In terms of lessons learned, the one point brought out was the need for stakeholder involvement. Somebody commented that it would have been better if we had done this earlier, but at least later is better than not at all.

GROUP 1: Lane Change and Merge Collision Avoidance

QUESTION: *Are Performance Specifications on the Right Track? If Not. What are the Suggestions for a Different Approach?*

Dr. Shladover: The answer here was yes, in general. It seemed to be heading in an appropriate direction. One thing that the group liked and pointed out was that it was being developed in a technology independent fashion. This resulted in technology independent specifications, yet remained cognizant of the technology limitations. This was a tough balancing act. Everybody recognized we have to consider issues of sensor coverage, detection probabilities, and false positives and negatives. It cannot be a totally idealized spec, neither can it be built explicitly around a specific technology.

Technology Independent Specifications

Standardized Definitions

There were a number of improvements that were suggested. One of the problems was getting to standardized definitions, and it was particularly challenging in this case. This seemed to be the most unstructured environment. The system is not just looking at a target ahead of you, or at the roadside along you. Rather, it must sense vehicles that are approaching your vehicle from different directions, and at different speeds. This one was quite complicated for that reason.

Justification for Data

We thought that we needed to have justifications for the values that were selected. Some specifications identified specific values, but the reasoning behind them wasn't necessarily identified as well as it should have been.

Coverage A reas

The coverage area addressed by the specifications included areas adjacent to the vehicle and behind the vehicle. There was a comment that we need to consider some coverage ahead of the vehicle in the adjacent lanes, as well.

A djustable Parameters

We need to identify which specific areas, and define which specific aspects of the performance should be adjustable by the manufacturer and/or by the driver. We also need to identify which ones should be rigidly required. This was, again, thought to be a fairly complicated issue because of the dimensions of this particular problem.

Cost/Benefit Tradeoffs

We need to be able to define the benefit/cost frontiers for use of such systems. If we are paying extra money for a certain sensor performance improvement, how many crashes is that going to enable us to save? People would really like to be able to see that type of a trade-off curve so that an individual designer of a system can find the right point on the curve and decide what kind of investment ought to be made. Related to that was some interest in having multiple performance contours, so that we wouldn't necessarily just have the ideal system that met everybody's needs. We might have 90 percent systems, and then we might have 99 percent systems; there was interest in having this range of levels of system performance.

There was also interest in showing what the hardware/software complexity trade-offs might be. You might be able to get by with simpler sensor hardware in exchange for more sophisticated data processing, but nobody really seemed to understand what that trade-off looked like, and there isn't available data yet to make a rational choice where to be on that trade-off curve.

QUESTION: *Will the Eventual Results from the NHTSA Work be Useful to System Designers? If Not, What Would be Useful?*

Dr. Shladover: In terms of whether the specification would be useful to system designers, the answer seemed to be a yes, in general. Some suggestions included the need to define models, and the assumptions used to link the sensor performance to the system performance. The ability to be able to express how some change in sensor range, accuracy or sensor coverage zone will translate into avoidance of crashes is not an easy task, especially in the context of this particular countermeasure. Some interest arose with regard to the process that would lead to industry-government consensus on the specifications.

QUESTION: *What Experiences or Lessons Learned can be Offered for Incorporation into the NHTSA Program?*

System Predictability

Dr. Shladover: In terms of the experience and lessons learned, we need to concentrate on the false and nuisance alarm issues. Again, this was thought to be particularly difficult for this countermeasure. Drivers need to have some uniform expectation of the performance of the systems. For example, if a driver goes from one vehicle to another, it should behave in a predictable fashion, or in a fashion that the driver can understand without needing some significant retraining because his own car had a different characteristic from the car that he was now driving. This was particularly urgent with respect to this countermeasure, because of the complexity of the environment, and the fact that we are dealing with things that are to your vehicle's side and rear - not just to your front .

Unintended Performance Effects

As before, we need to consider possible unintended side effects, such as new crash phenomena. If you get a warning about a vehicle that is coming up in one of your blind spots, are you going to take a correct action? or might you take an action that is going to get you into a different kind of crash from what you would otherwise have? **Some** of these issues are going to start looking familiar. They arise again and again.

QUESTION: *What Guidance can be Provided on Methodologies to Estimate the Benefits Which Would Accrue to Systems Designed to Meet the Performance Specifications?*

Documented A ssumptions

Dr. Shladover: In terms of benefits evaluation, we need to have well-documented assumptions. Merely stating the assumptions is not enough. We need to outline the reasons that those assumptions make sense, and demonstrate why those are realistic assumptions.

Comparison Cares for Evaluation

We need some realistic base cases for comparison with the vehicles equipped with this kind of countermeasure, and particularly with respect to driver behavior assumptions. What do we assume about the behavior of the driver in the equipped vehicle? What do we assume about the behavior of the driver in the approaching vehicle? There is a vehicle coming up behind you in the lane adjacent to you into your blind spot, and you are starting to make a lane change into that lane. How likely is that driver to back off because he sees you? How likely is he to not back off? Until we have a reasonable sense of that, it will be difficult to tell how many of those crashes are going to occur with or without the countermeasure. This is where we pointed out the need for refined estimates of the costs of the crashes that are occurring because of the absence of such systems so that we can then have a baseline for comparing what happens with these systems.

Evaluation Requirements

There is an interest in having a pilot test set of requirements defined to aid assessments once some initial systems are available for testing. Such requirements would potentially provide information concerning the kind of sample size we ought to have, how many vehicles should be involved in such a test, and what kind of measurements can be made to enable us to estimate the number of crashes potentially avoided by availability of this countermeasure. This is not at all an easy item, and we need clearly defined measures of effectiveness. How do we come up with the estimate of how many crashes were avoided?

There was a lot of ambiguity in the reported test results that were presented; some of those test results didn’t mean exactly what they appeared to indicate. Presentation of the test results needs to be clarified significantly. There was also interest in use of the “SAVME” tool for getting at lane changing times. What is the distribution of time it takes for different vehicles to change lanes? This is important since it affects how far to the rear you need to be able to see an oncoming vehicle that might be approaching at a certain approach speed. We had somebody point out the need for sensor testing in inclement weather. It wasn’t just a matter of testing sensors under good weather conditions.

GROUP 2: Run-Off-The-Road Collision Avoidance

QUESTION: Are Performance Specifications on the Right Track? If Not. What are the Suggestions for a Different Approach?

Defining User Population & Terns

Dr. Martin: Are the performance specifications on the right track? In answering that question, we first wanted to clarify who the users are. Are they end users, vehicle manufacturers, equipment manufacturers, or the public? Sometimes when we look for the specs, the specs are more specifically geared towards one of those groups. We should be looking at the public as the end person to making sure that our specs are geared towards giving them the results. In some cases, for example, with equipment, we questioned if "specifications" is the right terminology. For algorithms and concepts, "guideline parameters" might be a more appropriate term rather than specifications. Specifications seems to be a little bit too tight.

Scope of the Specifications

Should we specify 'the crash potential in time or should we do it at non-danger times? Should we only be doing it in the actuations? We discussed giving the driver continuous information rather than providing information only in dangerous situations.

For information from pavement specifications (the quality, size, and markings), should we be doing a spec on that or should we simply just say that the MUTCD standards and their application are adequate. Do we need to really specify the duration and accuracy that we specify? If we really need that, we may be able to reduce the amount of technology required to produce that item. The human factors people need to tell the equipment manufacturing people what that is.

Tailored Specifications

One of the things we were very adamant on is that the specs must be sensitive to the kind, size, and capabilities of each vehicle and its drivers. For example, truck drivers have been conditioned to do a number of actions almost without fail, such as checking the rear view mirror before making any maneuver. Automobile drivers frequently fail to do this. So, we might have a different level of specification that is required.

Our answers, most of the time, for the first question were that we were talking about whether the performance specs were adequate based on our experiences. I think most of **our** group assumed that these were just comments we were making rather than answering a yes or no. That tended to be where we came from.

QUESTION: *<u>What Experiences or Lessons Learned can be Offered for Incorporation into the NHTSA Program?</u>*

Public Acceptance

Dr. Martin: Getting to the next area about the experiences, public acceptance evaluation has got to be a major input into dealing with this. If we come up with the wrong technology and the public does not accept it, it doesn't make any difference whether it is great and it works; nobody is going to use it or everybody is going to find a button to turn it off.

Risk Compensation

Risk compensation was brought up several times. Experience, in particular with the European program Prometheus, is going to be very good input for our use (both in a global sense and, also, in a close proximity sense). The roadkeeping functions associated with the Prometheus work in Europe will also serve as excellent input.

Identifying Sources of System Faults

If the system does fail, what was the cause? Is it because it received improper information? Chemical bleaching of blacktop was cited as an example. In this case, the system determined that the vehicle had run off the road because it was not receiving the information that the sensors were expecting (the system detected the white roadway where it was expecting a black roadway and misinterpreted the situation).

QUESTION: *<u>Will the Eventual Results from the NHTSA Work be Useful to System Designers? If Not. What Would be Useful?</u>*

Technology Independent

Dr. Martin: Next we looked at whether the eventual results would be useful to system designers. This question was a little bit harder for us because we were looking at system concepts, and not design. The performance specifications are tied to the concept, and therefore are not technology dependent. This seems to be a reoccurring issue on all of these.

Staged Deployment

The last item dealt with articulating usable pieces of a technology. Staged deployment may be our best strategy - targeting first areas that have the highest "return" or at least acceptance. This approach allows us to build on other components rather than wait until we finish the entirety of that deployment area.

There was general agreement that researchers should seek out OEM's for application opportunities. In other words, come together, share information, and attempt to develop a consensus on what the items, requirements, and definitions are.

QUESTION: *What Guidance can be Provided on Methodologies to Estimate the Benefits Which Would Accrue to Systems Designed to Meet the Performance Specifications?*

Dr. Martin: As regards benefit estimation methodologies, **we think** that evaluating the ICC for ready-to-go benefits, will provide some quantification to this issue. So, we think that is probably **one** of the real methodology evaluations.

We should not assume that these technologies replace the human driver; they assist him. That is, until we get to the more intelligent levels of transportation. Acceptance is dependent upon making the benefits understandable to the public, so that they can see what those benefits are to them.

GROUP 2: Rear-End Collision Avoidance

QUESTION: *Are Performance Specifications on the Right Track? If Not. What are the Suggestions for a Different Approach?*

Dr Martin: Again, the first item dealt with the performance specifications, are they adequate? We were specific on some of these issues, and on others we stayed general. I think more of the general ones would be more germane and of interest to the group.

Where in the studies, or specifications, do we look at merging of all four parameters? The answer appears to lie in the development phase. How do general system changes impact our technologies, evaluation parameters, or sampling strategies. Take, for example, the recent change in speed limit to 70 miles-per-hour. We have been looking at operating speeds in the 55 miles-per-hour range. Should we be incorporating changes and effects into the specifications?

One question that was kind of nebulous to us from the perspective of rear-end collision avoidance systems concerns the vertical field of regard, is it defined enough to be very helpful? Our group thought that we did not enough definition as of yet. The old question came out that the vertical field does not indicate as strongly as some of the other field regards.

The most important one, I think, that we looked at was how do we communicate these countermeasures to the driver. It sounds like a reoccurring theme. I think that was something our group was doing, and we looked very heavily at that.

QUESTION: *What Experiences or Lessons Learned can be Offered for Incorporation into the NHTSA Program?*

Adjustment Options

Dr. Martin: Again, in the lessons-to-be-learned category. Specifications should allow for a graduated type of sensitivity, provided that there be a limited range of options. If we have an option as to whether the headway is 1.6 versus 2.5, there should be some sort of gradation so that you don't have drivers fine tuning it. There should be some defined headway options much like ride control (firm, normal, and mushy). Otherwise, we may find that drivers turn the system off under urban conditions because a given headway (adjusted for highway environments) just isn't realistic to deal with city traffic. There should, however, be very few fine tuning abilities, and these should not make it like a complicated stereo where you have woofers, tweeters, faders, backers. The system needs to have a limited number of options to be technically accepted; it must be able to accommodate differences between a rural situation and a very dense urban situation, for instance.

System In terface

Additional lessons learned relate to visual, audible, separate-type cutoff switches for driver acceptance. We may have drivers that determine that they don't like to listen, or be told, that their headways are getting too close; however, they would look at and respond to a light (visual display). The fuel level warning indicator was such an example. Those of you will remember that Datson had this system on one of their vehicles, the "talking" car. A light came on, and this nice little voice told you, "Fuel level is low..Fuel level is low." It repeated itself, and you turned it off and then rely on the available visual menu display.

One other lesson learned is that driver warnings should not cause additional attentional demands away from the main driving function. Drivers should be looking at the road, not trying to look at a warning device to interpret what it really means. That should be pretty self explanatory.

QUESTION: *Will the Eventual Results from the NHTSA Work be Useful to System Designers? If Not, What Would be Useful?*

Dr. Martin: Results that are useful for systems designers. Again, I think simulator results, as used for the ICC, will be very useful. One thing that was brought up was that the wordings of the specifications may need to modify the designer's view from a litigation standpoint-. Again, a particular item may have both a human factors aspect associated with it, as well as liability issues of concern to equipment manufacturers.

Public Perception

This next issue, I think, relates to all of the collision avoidance systems. It concernes the consumer's willingness to pay for a collision avoidance system (is it worth it to the public?). Again, this deals with public acceptance and perception. We talked about the perception of safety, from an equipment manufacturer's definition of safety versus NHTSA's definition, to a human factors definition. These may be different. So, we may need to do some "wordsmithing" on some of our agreements to that effect.

QUESTION: *What Guidance can be Provided on Methodologies to Estimate the Benefits Which Would Accrue to Systems Designed to Meet the Performance Specifications?*

Macroscopic View

Dr. Martin: The last item was to estimate the benefits associated with meeting the performance specifications. Our suggestion was instead of taking a microscopic approach to the net benefits estimation problem, we should take a macroscopic view. That is, looking at benefits in more of a broad sense, such as estimating additional benefits provided by system add-ons. This gets back into the crossover integration issues for total benefit evaluation. Because you have X, the benefit for Y is going to seem very much greater because you have X and Y in both the vehicles.

Risk compensation was mentioned again, as was the ability to look for staged deployment through the consensus of benefits. We must investigate which technologies are going to give us the greatest benefit, or the best public acceptance. This information should be drawn from the researchers, and fed back to the manufacturers and the public.

GROUP 2: Lane Change and Merge Collision Avoidance

QUESTION: *Are Performance Specifications on the Right Track? If Not, What are the Suggestions for a Different Approach?*

Dr. Martin: Are the performance specifications on the right track? We did not provide a direct answer, rather we provided a series of clarifications and comments.

Purpose of Specifications

First, the performance specs should help to define what the system is supposed to do and not how to build it. We also discussed what the definition of "blind spot" definition should be. Should it be used for all classes of vehicles, because the zones and the times are unique for each class. One issue that arose was that of defining the blind spot as a "proximity sensor detector detection area" rather than a blind spot because the vehicles are supposed to be designed without those.

The one thing in dealing with performance specifications that was fairly obvious to us from the information we received was the level of intensity and effort committed to backward and forward looking scan systems. More emphasis should be put into the blind spot scans.

QUESTION: *What Experiences or Lessons Learned can be Offered for Incorporation into the NHTSA Program?*

Driver Characteristics

Dr. Martin: Lessons learned. As I alluded to earlier, truck fleets sometimes operate a little differently than automobile drivers as a function of training. Commercial drivers, for example, almost always check the rear view mirrors and the side mirrors before making lane change maneuvers, whereas automobile drivers might not. This does not necessarily mean that their accidents are different, but it should definitely be factored into the performance specifications. If you are talking about dealing with CVO conditions, you must add slightly different driver characteristics to the specifications.

A udio Warnings

Another issue that was brought up was audio-type warnings. Will that call for us to use any less of our normal visual tasks because we have the audio ones? Are we not going to be looking as much in our normal visual tasks because we have the supplementary audibles?

QUESTION: *Will the Eventual Results from the NHTSA Work be Useful to System Desinners? If Not, What Would be Useful?*

Display Parameters

Dr. Martin: Information on display parameters will be useful to system designers. The premier issues were defining the display parameters (e.g., location, type, intensity, and symbology) that could be most useful to the system designers. What if we required a whole new symbology? Are we going to have to have a complete training system to teach drivers those icons? We may get non-use out of that.

Normative Data

One other suggestion was to use a normative driving behavior. We definitely need to make sure we include these data in the specifications. Two other items, which were more kind of noise background, is the amount, and frequency with which non-essential information is communicated to drivers. If trivial information is provided, drivers are going to simply block out certain useful information.

QUESTION: *What Guidance can be Provided on Methodologies to Estimate the Benefits Which Would Accrue to Systems Designed to Meet the Performance Specifications?*

Multiple System Benefits

Dr. Martin: On the benefits portion, we should include benefits for the other CAS's when they are combined (i.e., the lane change implications in safety will help in the rear-end part). We may have some cumulative improvements that, instead of being additive, are exponential. We need to have some ideas for that. It, again, gets back to the staged deployment. If we look at how these things could be added, the right combination of staged deployment being installed out in the field might give us some real sales points.

Another benefit is to show the utility of existing tools (i.e., the Monte Carlo technique). Are there limitations in the tool for further research? Finally, will the driver be better trained as a result of these new technologies? This may be an added benefit that we receive out of these systems; people who have these systems in their cars may end up being better trained.

GROUP 3: Collision Avoidance Systems

Mr. Freedman: As I indicated earlier, our group noted so much commonality in the issues associated with each of the three collision-avoidance systems that we decided to present them as general issues and responses to the four questions rather than breaking them down individually by collision avoidance system.

QUESTION: *Are Performance Specifications on the Right Track? If Not, What **are** the Suggestions for a Different Approach?*

Mr. Freedman: Regarding the question as to the performance specifications. One of the overriding concerns across all three systems was that the performance specifications lacked the backup detail that is needed by the designers. It is understood that these specifications are in a relatively early stage of development; however, designers are moving ahead - advancing designs, promoting development of these collision-avoidance systems, and developing information on their own. They could certainly have the benefit of more detailed information from the contractors who are developing these performance specifications for NHTSA. So, the information providing the backup behind the detailed specifications is needed as soon as possible by the designers.

A dded Detail

Performance, Not Design, Oriented

Further, some specifications were believed to be too oriented toward design specifications rather than performance specifications. One of the examples that came out in the context of rear-end collision avoidance systems was an under-hood operating temperature range design specification. The comment by one of the motor vehicle designers was, "Well, these sensors, or systems, might not necessarily be located under the hood. They might be placed somewhere else in the car. So, don't constrain us in that manner to such design specifications. Open it up. Make them more performance specification oriented."

Specifications vs Guidelines

It became clear after examining the present performance and design specifications, as well as hearing comments regarding all of the collision avoidance systems, that the current set of specifications are really a combination of things (guidelines, performance specifications, design specifications, etc.). There are some broad guidelines like, "system should be able to perform under all weather conditions," and they "should be able to recognize all vehicles manufactured in the United States," and they "should be reliable," etc. Those are more guidelines than anything else. Then there are performance specifications that indicate, let us say the range of sizes of vehicles that need to be detected. Those are more towards performance aspects. Finally there were design specifications that in some cases were felt to be overly restrictive or unnecessary. So what we have presented to us now is a combination of these three kinds of guidelines and specifications. You have already heard from the other two presenters that specifications, when they are true specifications, should have test procedures that are recommended so that the efficacy of the systems can be tested. This ensures that one can determine whether a developed system does meet the guidelines or specifications.

Reliance on Simulation

Another comment was that although the specifications were generally in the right direction, often the details that were presented that went along with the specifications depended much too heavily on simulation. Often the decisions that went into those simulations weren't necessarily clearly provided, at least not in the material that goes along with this workshop. I am sure interim and final reports will document many of the decisions that went into the parameters associated with simulation, but they are not clear at this point. If performance specifications are built largely around simulations, then those details certainly need to be known. Moreover there is, also, a great need to go beyond just simulation to get some field testing under way and use the results of field testing for final development of performance specifications.

A djustable Range

Finally, when a performance specification is presented for a system that is user adjustable, the range of system capabilities (or the range of detections or performance) needs to be presented to drivers. Further, the amount of adjustment that a user can make should be bounded at the upper and lower end. It should not be infinitely adjustable; only to the extent that it needs to be in order to function properly.

QUESTION: <u>*What Experiences or Lessons Learned can be Offered for Incorporation into the NHTSA Program?*</u>

Specification ' "Models"

Mr. Freedman: What are some of the lessons learned that are applicable to performance specification development? Well, there was discussion about current federal motor vehicle safety standards. Some of them are very much performance oriented. The development of air bags was frequently cited as a good example of a performance specification. The air bag specification is essentially as I understand it, built around what an air bag is supposed to do in terms of protecting an occupant, not necessarily on the kind of stitching that goes into the air bag, or certain highly detailed design specifications. Similarly, the brake system motor vehicle safety standard is built around a specification on stopping distance. That is a real performance specification and a good example for the way performance specifications should be structured.

Response to Warnings

Another comment on lessons learned had to do with the question of how drivers respond to warning systems in general and certainly more information is needed in that area. The comment was that we can see that drivers don't always respond very well to warnings that are presented now (e.g., low fuel warnings in a vehicle display). Drivers don't necessarily respond well to yellow warning signs on the roadway, and certainly not to speed limit signs. There is a need, then, for human factors studies to better understand how drivers respond to in-vehicle warnings.

Driver Training

Finally, another lesson learned could come from the anti-lock brake system experience. It is now generally recognized that anti-lock brakes are surprisingly less effective in reducing crashes that was expected. One of the notions emerging from this is that anti-lock brake systems may require more driver training in their use than has been provided. This may be the focus of some ongoing research and should be for future activities. The same thing is likely to be true of collision-avoidance systems in vehicles; drivers need training to understand the messages and how to respond to them. We may not see the benefits unless drivers really know how to use the systems.

QUESTION: *Will the Eventual Results from the NHTSA Work be Useful to Svstem Designers? If Not, What Would be Useful?*

Integrated Specifications

Mr. Freedman: Will the results from the NHTSA work be useful to system designers? Generally yes. That was a general group conclusion, but again, as these individual systems become further and further developed, and as they are integrated into multiple collision avoidance systems, there will be a need to broaden these specifications so that they include the integration. When there are multiple warnings that can be sounded or displayed visually or haptically, there will eventually be a need for them to be integrated; specifications for individual systems will have to be merged in some useful way into a specification for an integrated system.

Legal Aspects

Lots of questions came up about legal aspects, particularly for specifications that are worded in such a way that dictates that the system must work under all conditions, OF with fewer failures than 1 in 1 million. These need to be well thought out and carefully worded. In terms of evaluation, there is a need to better understand the trade-offs of system cost versus performance. Again, those kinds of details aren't yet being presented, certainly not in the performance specifications contract reports that are available. Perhaps they will be at some point in the future. A strong cautionary advice from the vehicle design community and vehicle manufacturers: be very careful not to overspecify performance. One does not want to necessarily limit improvements or innovation in design by overly specifying systems in too restrictive a manner. Yet minimum performance requirements to ensure reliability and effectiveness are necessary.

Speed Deployment of Specifications

Finally, it was noted that despite all of the activity that is going on under NHTSA direction, designers are moving ahead with system designs of their own. There is a great need to make the information developed under the NHTSA contracts available to designers as soon as possible. If there is any way to move up the presentation of reports or data to get them into public hands, that would be appreciated. If not, specifications may be somewhat late with regard to what individual designers are doing. The detail behind the specifications may come out even later, and consequently the final specifications developed under government contract may be less relevant than they could have been had they been available earlier.

QUESTION: <u>*What Guidance can be Provided on Methodologies to Estimate the Benefits Which Would Accrue to Systems Designed to Meet the Performance Specifications?*</u>

Normative Data

Mr. Freedman: For benefits estimation probably the highest priority factor had to do with providing normative(baseline for unequipped vehicles) data. This is where some of the research tools that were presented earlier today become very important - especially the vehicle motion environment device and DASCAR. These tools can provide normative data against which modeled or measured performance of vehicles equipped with these collision avoidance systems can be compared. Understanding the basic vehicle motion and driver behavior parameters is necessary to design the collision avoidance systems. So. there is a fundamental need for normative data both for evaluation and design.

Surrogate Crash Measures

Related to my earlier comment on driver responses to traffic control devices, there is a need for information on how often drivers comply with or ignore warnings in real-world environments. If surrogate measures for crashes, such as driver response frequencies, are going to be used in benefits estimation and evaluation, there is certainly a need to clearly understand how these surrogate measures relate to crashes. That level of understanding doesn't yet exist even for things like traffic conflicts which have been well studied over the years. Finally, for any benefits evaluation there needs to be a thorough documentation of all of the assumptions that are used to calculate frequency of occurrence of crashes, or near misses, and certainly of the costs associated with them.

Mr. Farber: Mark, thank you very much. I think we owe a round of applause to all the presenters. (Applause.). These were very clear and precise presentations, and I appreciate it. I observed that a lot of the comments tended to be quite global, but I guess that is because the questions were global.

Summary

The table below summarizes key responses to each of the four questions posed to meeting attendees for each of the collision avoidance systems. Responses were consolidated across breakout session groups (Appendix C presents written survey results for each of these issues).

Summary: Responses to Issues by Collision Avoidance System

	Collision Avoidance System		
	Rear-End	Lane Change/Merge	Run-Off Road
Are the Performance Specifications on the "Right Track?" If Not, What are the Suggestions for a Different Approach'?	- Yes, generally in the right direction. - Specifications should be performance based and define system limitations. - More background detail and rationale is needed. - Some design specs are too restrictive. - Minimum performance requirements are appropriate and necessary. - Need specifications addressing human factors aspects. - Specifications should avoid setting artificially high levels of performance which cannot be achieved. - A range of performance capabilities for user adjustable CAS are appropriate. - A need exists for more real-world testing to establish performance specifications. - Specifications need to address performance under degraded operating conditions - Indicate relationship between system performance and system effectiveness.	- Yes, in general. - Definitions need to be standardized. - Specifications need to be technology independent. - Tradeoffs in performance/cost need to be considered. - Define system parameters which can have an adjustable range.	- Performance specifications should be based on system performance, not components. - Must define user population. - The scope of the specifications needs to be defined.

	Collision Avoidance System		
	Rear-End	Lane Change/Merge	Run-Off Road
What Experiences or Lessons Learned can be Offered for Incorporation into NHTSA's work?	- Drivers do not necessarily respond well to existing warning systems. We need to better understand what drivers respond to regarding warnings. - Driver training may be the key to effectiveness (system evaluations have to account for this). - Design-oriented specs are less flexible than performance oriented specs. - Initial assumptions do not always correlate with reality.	- Leverage research on false & nuisance alarm issues. - Recognize potential for systems to create new crash effects. - Examine comparable systems (e.g., TCAS in aviation). - SAVME useful for information on lane change times. - Take characteristics and differences of driver populations into account.	- Consider legal implications. - Talk to the end user to gain acceptance and insight. - Track road conditions. - Consider risk compensation. - Identify underlying causes of system faults.
Will the Eventual Results be Useful to System Designers? If Not, What Would be Useful?	- Generally, yes. - Need specifications for integrated systems. - Questions regarding legal aspects, costs. - Do not overspecify performance. - Designers are moving ahead, guidance is needed now if specs are to be useful. - Emphasize user interface design.	- Yes, in general. - Significance of test results must be clarified. - Process should lead to industry/government consensus. - Define models with assumptions. - Include normative driving behavior in the specs.	- Yes, to the extent **that** future designs mirror the original system embodiment. - Consider staged deployment as a strategy for building acceptance.
What Guidance can be Provided to Estimate the Benefits Which would Accrue to Systems Designed to Meet the Performance Specifications?	- Need information on the applicability of surrogate crash measures. - Need thorough documentation of assumptions. - Need normative data. - Need a clear statement of crash types. - System usage data needs to be obtained. - Adopt a broad macroscopic view.	- Need well documented assumptions. - Need realistic base for comparison. - Need to specify pilot test requirements. - Need clearly defined measures of effectiveness. - Examine overall integrated system benefits.	- Need normative data - Need surrogates (lane excursions, lane position, etc.) in effectiveness testing.
General Issues/Other Comments	- Specifications lack the back-up detail needed by designers. - Some specifications are too oriented toward design rather than performance. - The presented specifications are actually a combination of guidelines, performance specs, and design specs - each has different requirements. - Specifications should have defined tests to validate compliance.		

QUESTION AND ANSWER SESSION

Mr. Farber: We are going to throw the floor open to questions. We have about 25 minutes. So, if anybody has a question, please, now is the time to bring it up.

Q. One comment raised earlier was that we need more information on how much drivers conform to, or ignore, warnings. We have got to use the words "ignore the warnings" carefully. You can conform to a warning. Alternatively, you can perceive the warning, make a judgment, and decide not to do what the warning recommends.

A. Granted it probably would have been more wisely worded to say that we need to better understand the extent to which drivers use the warning information that is provided to them. Thank you.

Q. The contractors were specifically tasked with investigating both the warning systems and systems that provide control intervention. In several of the lane departure sessions we found that some people, particularly OEM's, were reluctant to even consider active control intervention. I was wondering if that was a general attitude common to all the different collision countermeasures, or is that specific to lane departure countermeasures?

A. In our group, it only came up in the context of lane departure. It really didn't come up in the others. I would offer that may be because the lane departure countermeasure was the only one that essentially offered to initiate a controlled response. It wasn't just vibrating a gas pedal or a steering wheel. It was actually providing a small steering input initially whereas the other systems weren't really described in that context. When you start changing lanes, using steering corrections, you really have to know everything around you before you can even consider executing such a maneuver. This is, in my view, a far more difficult problem than is automated highways.

Q. I have a question for the panel. The discussions of benefits have been couched largely in terms of avoiding accidents, but at least for some of the countermeasures it is possible perhaps not to avoid an accident but to reduce the severity of the impact. Somebody once observed, and I think he is absolutely right that in the case of rear-end collisions, that it is more important to turn a serious crash into a minor crash than it is to eliminate the minor crash. I wonder if any of you have any observations on that?

A. I think, yes. One of the items that I didn't mention in our discussion concerns additional benefits. One of these was roadway capacity which really is a safety issue. There is always this fear that drivers will slow their speeds down (thereby reducing lane capacity) without some sort of system that would monitor, respond, or notify drivers that a lane changing is not a safe maneuver at this minute. I think we are going to be able to increase capacity with the use of systems which enhance situational awareness. Drivers will be operating with a little more assurance with access to this type of information. So, we may perceive increased capacity, and better trained drivers, as one of the benefits of these systems.

A. I wanted to pick up on the issue of capacity and safety. One of the things that did come up in our group was the observation that much of the driving that occurs today is at spacings that are shorter than the spacings that these forward collision warning systems would be recommending. If we really did have systems that were giving warnings of safe spacings, we would either be irritating the hell out of the drivers, or we would be reducing the throughput of the system because we would be requiring the vehicles to run further apart. To get back to Gene's question about mitigating the severity of the crashes, I think that would be great. I think the challenge is how to estimate how effective we might be at that. It is hard enough to try to estimate how many of the crashes might we avoid, and I suspect estimating how much we would reduce the severity is going to be even harder. I think that is the greatest challenge we are facing right now; how do we come up with supportable predictions of the effectiveness of these systems?

A. There are also disbenefits to be considered. Some of those may accrue from driver behavior modification as they come to learn how to use and depend on these systems. There may be great changes observed in the kind of normative behavior as more and more vehicles in the fleet are equipped with these devices and more and more operators learn to use them. Now, whether that will result in reduced crash frequency and reduced crash severity; well, there are questions as to what extent crashes will be reduced and offset by other kinds of unanticipated crashes.The other item I wanted to add is that these collision avoidance systems also offer opportunities to enhance occupant protection. Since these are, in some cases look-ahead systems, they are capable of sensing imminent crashes. There may be some opportunities to actively engage or prepare the protection systems, such as occupant restraint pretensioning, seatbelt pretensioning, or adjustments to the deployment rates of things like air bags. So, again, this applies to the notion of reducing the severity of crashes as well.

Q. These systems can be conceived of having a range of operation from just helping the driver maintain situational awareness and enhancing the driver's perception, to being a warning system for imminent conflicts. If we just make this a warning system, I doubt if the driver is going to be ready for these rare warning events. At the other extreme, you can have something that is a little bit like a speedometer that is always present; you can look at it and monitor how well things are going. I think the best systems are going to embrace this whole continuum. At one end, they are going to be continuously monitoring and enhancing the driver's perception and situational awareness, providing the driver a warm feeling that things are going okay. At the other extreme, they will actively communicate critical events to the driver. I would like to hear some comments from others about that.

A. I think we are at a very early stage in the process of developing and understanding driver behavior. We have very limited experience with warning systems in vehicles. Radar detectors may be one example that can be used, but it is a very limited warning system. In addition, drivers are highly focused on radar systems because they perceive that when a radar detector goes off in their vehicle, there is a reasonably high probability that there is some enforcement activity ahead. So, they respond to it because there is a consequence to this warning. There haven't been enough of these collision avoidance systems deployed in real-world situations to have a really good model of driver behavior in response to warnings that are rare but serious. Again, going back to the radar detector model. These systems have an urban versus rural switch (or an open road versus city switch) on them because it is understood that there are lots of false alarms in the city areas, and drivers will ignore them. I think it is too early to really know yet what driver responses are going to be to system warnings. They have been studied fairly well in the laboratory, but not yet with deployed real-world systems.

A. The stereoscopic system is one of the examples discussed in our group which really drives home the fact that we need to focus on the amount of information, and the manner in which information is provided to drivers. In the context of run-off-the-road, the stereoscopic system uses the vehicle's stereo speakers to issue a warning. If you start to pull off to the right-hand side of the road, for example, the system would sound a horn originating from the right-hand speaker (instead of just an annoying beep). So, when you hear a horn to your right, you instinctively make an adjustment to move to the left. This is accomplished without use of any lights or sophisticated displays. Now you have accomplished what no icon, any set of arrows across the dashboard, or any jerk of the steering wheel could have done by simply placing the sound in an audible location where the driver anticipates that he is going to hear it, and reacts normally to it. We often try to complicate these interfaces simply because we have the technology to do it. This was a good example of how a simple type of auditory tool can accomplished all of the other things that could have taken a large amount of technology to do.

Q. Let me bring up one other issue. I think it was alluded to in a couple of our sessions, but it is the issue of training drivers to use and understand the systems. I think these are qualitatively different systems than we have ever had in our vehicles before. I think the only system of comparable complexity is the cruise control, and they are actually quite simple by comparison with these systems. These systems are all going to have limitations or none of them are going to be perfect, and it may be that driver understanding of what these warnings mean and how the systems work may not be perfect. Does anybody have any ideas about how manufacturers or any other entity, public or private might help to make these systems more effective by ensuring that the drivers who use them understand what the systems are supposed to do and how they operate?

A. The tank automotive command, I took six army vehicles on a 3000-mile convoy across the East Coast with, four of the vehicles had collision warning. Two of them had intelligent cruise control, and in all cases the National Guard drivers who had never seen those systems before in their driver survey said that in about 2 hours they felt comfortable with them and knew how to operate them, and for the first hour they were extremely skeptical that this made any sense at all. That is part of the training. The other part of the training is if you want to sell these how do you convince the driver to shell out the money initially for something that he doesn't have a clue as to how it is going to benefit him.

A. I think that last comment is a really good one because there is, also, the question of what is going to motivate the salesperson at the dealership to want to get the customer to try it, and how long a test drive are they going to have to take to convince themselves that this is something they really would like to have. Maybe we can look to some of the overseas experience as these things start coming on the market in other countries and learn from that because obviously there is one on the market in Japan now, very limited volume, and there are likely to be others coming on the market there and in Europe.

Q. I will bring up one final issue. It seemed to me that for estimating benefits until we are at a point where we can put fairly large numbers of vehicles on the road, the only way to estimate benefits is to do modeling that is informed by good field testing and experimentation to fill in the details. It occurs to me that really the only thing you can do in pilot testing even with fairly large fleets is to try to assure yourself that you are not going to cause a demolition derby when you put the system out. To get accurate estimates of benefits you need very large fleets operating for long periods of time as those of us who have been, who follow, for example, air bag effectiveness assessment can attest. I just wonder if anybody has any thoughts about mathematical modeling and who ought to be doing it and what the major issues are. Comments from the panel?

A. I think the answer is data, data, data; more so than model form. How do we come up with the data that we need to make the realistic models? Running through the math is not so complicated, but coming up with the data to formulate the models, I think, is really going to be very challenging.

A. I would say that right in line with the need for data is the need for knowledge regarding the various parts of the system that together produce the driving environment. That is, data on driver behavior and responses, both normative and in the presence of a collision avoidance or collision warning system. If you are going to run Monte Carlo simulation, for example, one needs to know the distribution of the relevant aspects of the driving environment (how many miles of road of this type? how often are curbs encountered?). There is a great deal of normative data that are required, as well. Clearly, there are data that are needed the define the vehicle operating characteristics with and without the collision warning system. So, vehicle and driver data are both required.

A. I agree with everything that the panel has been saying. We really need more data. What I would like to suggest is that we need the data as quickly as possible so that we can more actively in a evolutionary fashion, develop performance specifications and determine the benefits to the systems. NHTSA will soon be coming on line with a lot of tools that will help do that. DASCAR, for example, could generate a lot of good data in conjunction with field testing, and limited field testing of the systems. We need as much normative data as quickly as we can get it to support the modeling process.

A. I would like to add that in the quest for normative data, one has to be very mindful that we don't go out in a sort of haphazard way and just run up and down as many roads as we can think of and gather data. There really needs to be a very careful plan for the collection of normative data that is statistically-based, sample-frame-based, etc. Data must be gathered in a meaningful way so that it will be useful, applicable, and generalizable to the driving environment throughout the United States.

A. I think there has to be a realization that the people who are actually going to buy these systems are the public. We have got to have input into this. The Greyhound example highlights problems dealing with acceptance.

A. I will just make one comment on modelin g and that is that there is nothing better for telling you what data you ought to collect than having a good well-founded, well-thought-through model.

Section IV: Summary and Closing Comments

Dr. Kanianthra: I think this workshop has been extremely useful, at least from my vantage point. Most of the comments we received have been very, very constructive. We made a start with the performance specifications. Now, where you take it from here is essentially in the hands of August and the staff. I think we are going to certainly take a stab at how to handle these comments, and you will see some final products later on. I want to make one comment regarding some of the comments you made regarding the specifications. I sense that some of you feel that anything which ends up in the hands of NHTSA always ends up in a regulation. I don't see that happening in the area in crash avoidance because the driver is in the loop, and this represents unknown quantity as far as NHTSA is concerned. That is my personal view.

Regarding our data. I heard a lot of requests for data. My concern is that while data are certainly very good (the more the better), what can we do with what limited data we have? Is it possible for us to estimate benefits of any kind? I think it is solely a degree of precision. If we have more data we will probably achieve more precise benefit estimates. If we don't have enough data, we may be on the crude side. I think somewhere in between is probably what we need. I don't think we will ever get to the level of 100 percent accuracy for benefits. Secondly, what are we going to do with these benefits? We need the benefits, not for regulations, but for the public. If the public see's some benefits, maybe they will accept the countermeasures we propose.

So, from that standpoint, benefit estimates have to be realistic. They do not need to be precise. These are my views. Bob Ervin is here to tell it like it is. So, let us hear what he has to say about the workshop.

Mr. Ervin: I was quite struck by a comment Dr. Martinez made. I wrote it down verbatim. He said, "NHTSA is seeking an orderly and scientific manner of solution to making our way toward crash avoidance products for sale in the US." He turned to Bill Boley and said, "And Bill seems to have this term 'after the true problem'." I don't really know what that meant, but, yes, that is the kind of stuff we need to hear (see Viewgraph 1, below).

NHTSA

Seeking an orderly and scientific manner of solving "The True Problem"

Prescribed Method for Developing Specifications

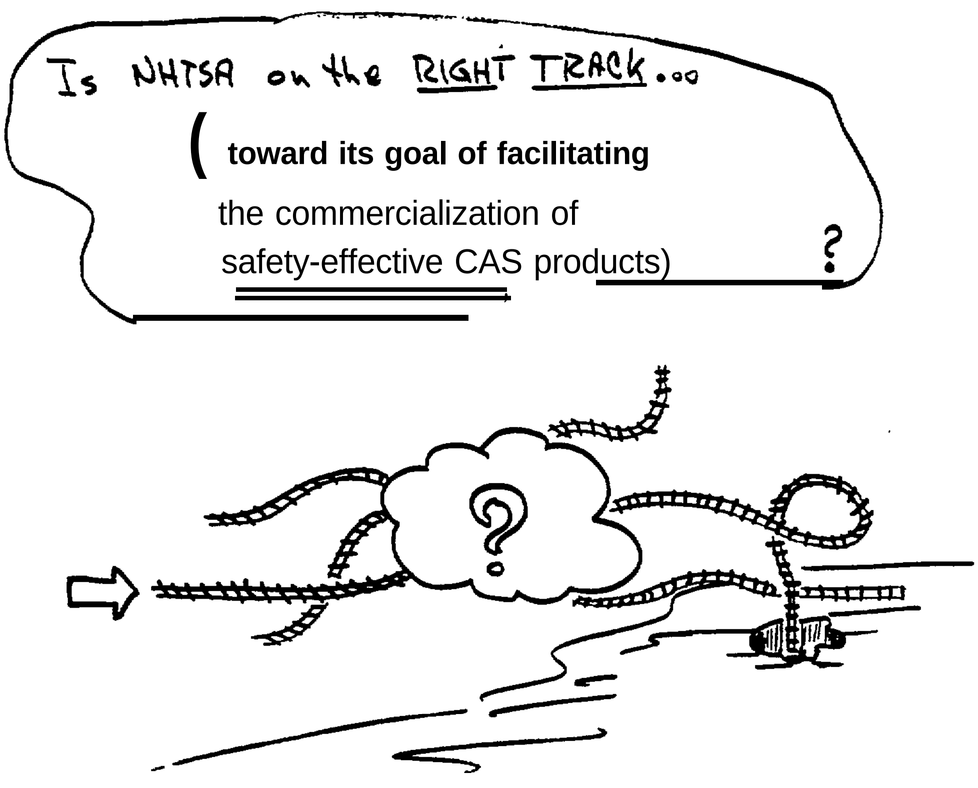
Entirely Forthcoming

Viewgraph 1.

We really want to know what the true problem is. Of course, everybody has his own little private kernel of what he thinks the true problem is. One of the big struggles that we have is that each of us has a little different mental model as to what we think the problem is. So, our estimation about how hard or how easy, and what work is required, is reflected in what each of us estimates is the true problem. I am going to make some further comments on this issue of the mental model that each of us has of what we think the problem is. By that I mean the various problems that we have partitioned out by crash modality, and by the type of system that may address each of those modalities.

When August got up, he basically said, "Look, NHTSA prescribed what these contractors were to do in some rough sort of tasking sense, and they are here to report on the first phase of something that has three phases." Then Gene said that NHTSA is really very forthcoming in having an event like this; they laid out their work for our scrutiny and peer review. When I first heard peer review about 8 months ago, I said to Bill Leasure, "Gee, Bill, do you really mean it?" In the university environment peer review means you are going to seek those that know enough to tell you what you really need to hear, although you may not want to hear it. I think that it is merciful for the contractors in this particular case, that nobody knows. Nevertheless, from NHTSA's point of view it was a risky thing to do.

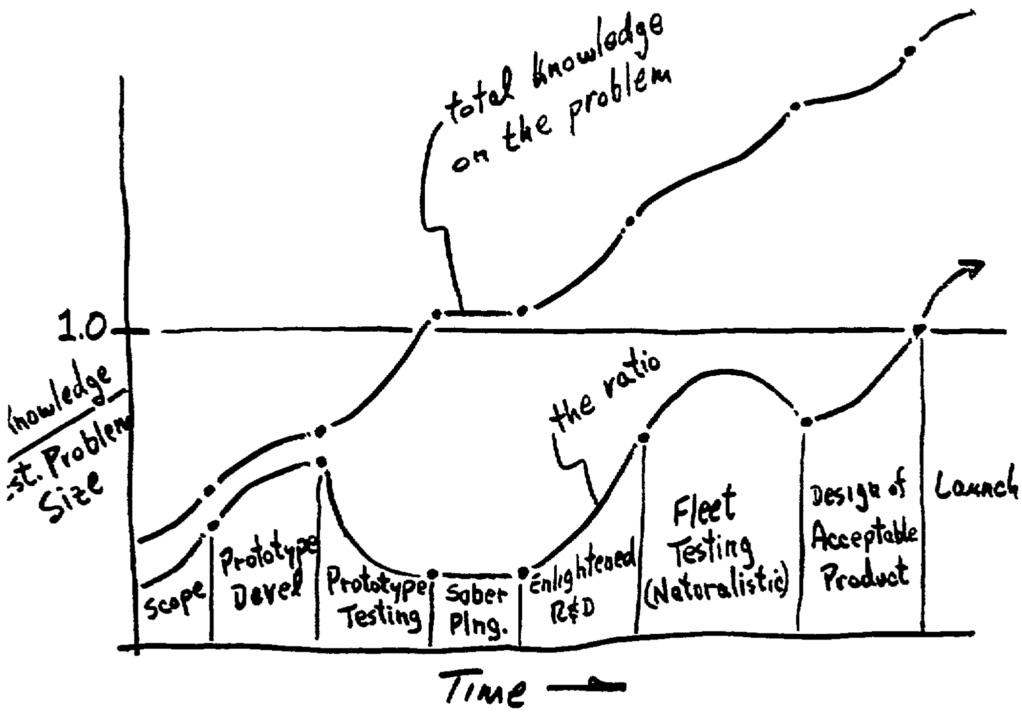
Is NHTSA on the right track toward its goal of facilitating the commercialization of safety effective crash avoidance system products (see Viewgraph 2, below)? I think that this is NHTSA's goal in this arena, if you read their strategic plan of 3 or 4 years ago. It is really only NHTSA that concerns itself with whether the motor vehicle is yielding safety-effective outcomes in consequence to its design. The auto makers will have a corporate concern for these things (concern for their customers at a professional level), but there are other agendas and concerns.



Viewgraph 2

Okay, what can we say about this benefit thing. Are we fairly convinced that we are orienting this towards a safety payoff? What track are they on? At least before us they said, "We took a track that currently has two parts." One part is a bunch of specification projects that are crash-mode specific, and the other track is some investigative tools that are intended to have the basic capability to generate new empirical knowledge. This is a very reasonable endeavor. We are not losing ground with writing specifications; we are gaining ground. However, I know that there is a lot of possible conflict in the philosophy of specification writing. I don't think anybody really worries at the moment that NHTSA is moving toward a resurgence of the early seventies. Let us simply say that in this ball game right here, facilitating the progress of the technical community and the commercial community by means of spec writing is the approach tool that NHTSA has selected to help move the process along.

I think it is very possible that if we weren't doing some of the type of work that NHTSA is engaged in, we might end up with a kind of a pedestrian outcome. I have tried to diagram where we are relative to this knowledge issue, and have cited certain stages that we might encounter as we proceed (see Viewgraph 3, below). On this viewgraph, I have plotted the ratio of our current knowledge level to the estimated problem size.



Viewgraph 3.

Let's take rear-end crash avoidance, for example. What do we think is the amount, and size of this problem ahead of us? What are we going to need to get on top of, or subdue this problem, and make our way on over toward launching products (at the right). I believe this progresses in stages. First, we attempt to scope out the problem. This I would say is what the "specing" projects are accomplishing. Some of the projects are also directly engaged in prototype development. Either people handed them prototypes or the investigators themselves did some prototype development. We learn a lot by developing prototypes. Both the ratio of knowledge to estimated problem size and total knowledge increase with the development of prototypes. However, as we take the prototypes out in the public highway, our estimate of the problem size tends to grow enormously. As soon as you take a prototype out into the real environment, and you encounter real traffic in all of its glory. Consequently, the ratio tends to take a real hit. So, we get sobered up, and we decide whether to continue. There is more enlightened R&D, and then we get to fleet testing. Eventually we decide the thing really works, and we get to the point where we say that we are ready to perhaps address the productization issues: How are we going to manufacture the sucker, make a product out of it and so forth? Then we launch.

I kept hearing the issues of warnings arise over and over again for each of the crash avoidance modes being addressed. Much discussion was generic. It didn't seem that each of the contractors had really looked carefully at the generic warning-related work that has been done (see Viewgraph 4, below). I am thinking about the COMSIS work, for example. I realize each system that is going to deliver a warning has to address this generic base of knowledge, but should we have to revisit it as if we are starting over again?

WARNINGS

Need to address generic warning guidelines off-line
(follow-up to COMSIS work)

BENEFITS ESTIMATION

Rumble strip case
Monte Carlo Simulation
- acknowledges stochastic content,
- structures the problem concept,
- guides empirical work

DISCUSSIONS EMPHASIZED SYSTEM FEATURES

They're engineers
They bought in to NHTSA Program

Viewgraph 4.

I was tickled by the rumble strip case that CMU mentioned as one means of scaling benefits estimation. Here is a real world case that seemed to present an interesting analogy to the warning implementation that would be done technologically inside the vehicle. I don't know anything about what exists in the literature on rumble strips, but apparently it is not too satisfying. Somebody ought to put some money into studying the rumble strip case properly, rather than worry over the fact that the only data we have on rumble strips is not good.

A variety of discussions about Monte Carlo simulations appeared, both in the TRW presentation on the lane change aids, and in the Frontier presentation on the rear-end systems. I thought this was a valuable element to be introduced into the package. The reason we model anything is firstly to express in a structured way our understanding of the problem. So, our understanding is increased to the extent we can use this form of simulation. I am not saying that we should go bless the specific models that were produced. I haven't looked at them, but that kind of approach has merit for its structure and for the guidance it can provide, particularly in identifying and prioritizing the type of empirical work which needs to be done.

Steve Young made a comment about TRW intending to go and use a new laser scanning system to collect normative driving data of people driving in adjacent lanes. This data would be used to generate an empirical database to provide some authority into the way they want to model lane change aid functionality. That makes a lot of sense to me.

VME is not delivering data yet. It will be a year and one-half away or so. That is the same kind of thing that I see that we have been able to do recently in the context of adaptive cruise control. You put the sensor on the front of the vehicle. You turn off the adaptive cruise control, and you get a bunch of people to drive it manually, and you collect data on how they maintain headways, how they pass others, their closure rates, and how close they get before they pull out to pass. All that information is right at the core of how the system will work if it has to live in the environment where people drive. So, we now have sensors that are meant to be part of crash avoidance systems, but can also be installed on research vehicles. That is an enormous opportunity.

I would say that about 50 percent of the breakout group discussion was at the level of what I would call features; discussions concerning the features of these systems, and how they work. So it seemed to me that there was a certain implicit sort of affirmation of what NHTSA had done by the fact that so many people were willing to just dive right in, and proceed to talk about the details.

I posed a question about how the NHTSA specification process will operate in the future vis-a-vis the initiatives of the ISO/TC 204 Committee, working groups 13 & 14.1 have been impressed with what working group 14 has been structuring on adaptive cruise control, for example. There is a lot to be gained there. I think in the future we should show where NHTSA's specifications stand vis-a-vis the corresponding specifications that are coming out of the IS0 work (see Viewgraph 5). It seems to me we have a sort of responsibility to show how things that we are doing stack up against what others say is important.

NHTSA Spec Process Vis-a-Vis ISO/TC 204

- At least show correspondences and differences
- Reflect on long-term aspirations

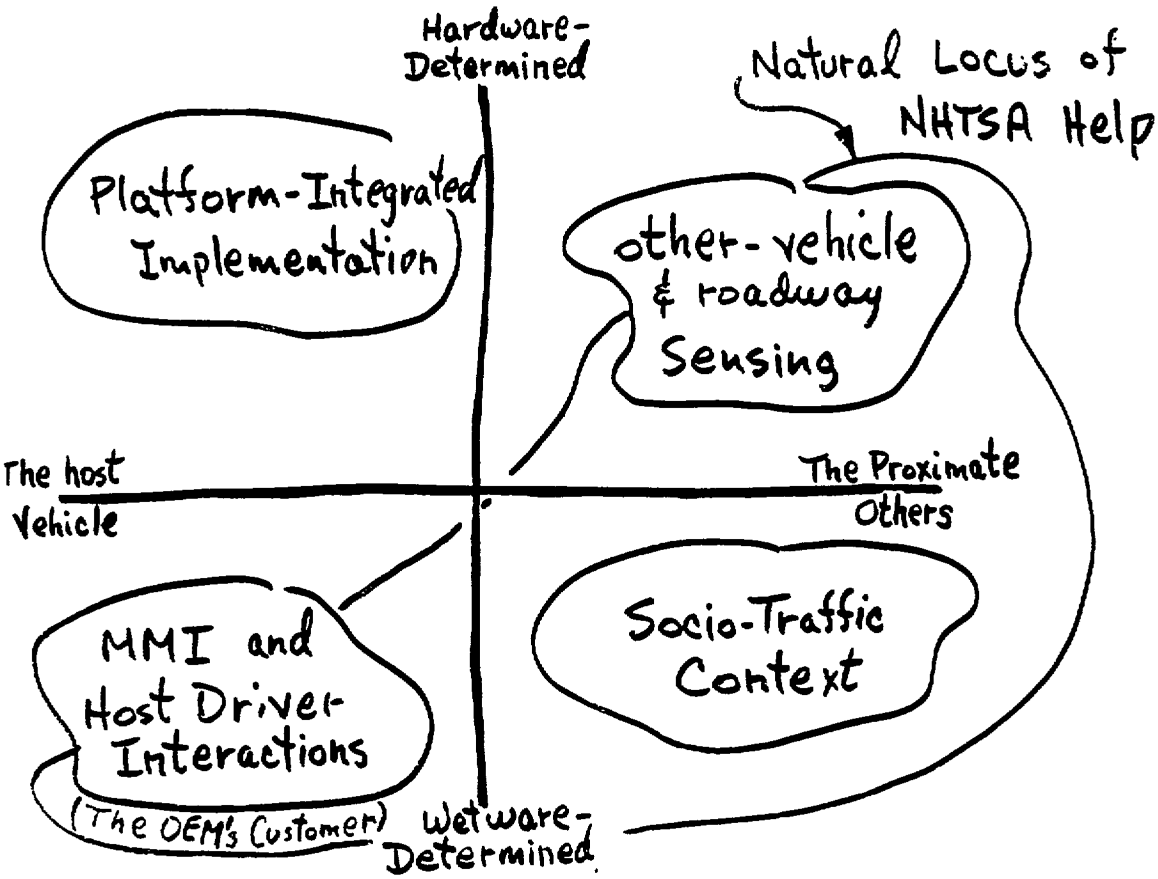
Designers Moving out NOW!

Platform chiefs, too?
Priority across system types

Viewgraph 5.

Clearly though one could look at the initiatives that are going on in industry and say, "There are some priorities." Well, all right, what are they? I think many know what some of them are because there are people in different sectors of the world that look like they are preparing for products of certain kinds already. There is probably some loose consensus that says some of the things we have talked about are pretty far in the future and no one will suggest that the designers are moving out now with regard to those kinds of items.

I thought about the second question, "Is this stuff helpful to designers?" Or you might say, "Is this stuff helpful to that industry from whence these products will spring?" I took a crack at outlining this issue using a pair of axes that circumscribe the requirements for automotive systems (see Viewgraph 6, below). The vertical axis on this figure represents the span from hardware-determined to "wetware"-determined considerations in system design. By the wetware, I'm referring to those aspects of human cognition and behavior which determine the interactions of the individual with the system, while driving. The horizontal axis represents the range of system considerations spanning from those exclusive to the host vehicle itself (on which the system is to be installed) to those pertaining exclusively to the "proximate others" - that is, other vehicles and the roadway features that are relevant to the immediate (safe) operation of the host vehicle.



Viewgraph 6.

Firstly, we recognize the upper quadrant as the space that has traditionally been the chief concern of auto manufacturers. As the vehicle becomes friendlier and especially when it becomes equipped to assist the driver in conducting information and control tasks, the system requirements in the lower left quadrant come increasingly into play. This lower left place will be of prime concern to the automaker in the development of information and control aids since this is where his customer lives. If the system is going to interface directly with human thought and perception, it must be eminently satisfying to the broad population of customers. Otherwise, warranty claims and/or a paltry market acceptance will occur.

The right-half plane is an altogether new ball game for automotive systems. It is here that the dynamic reality of traffic will impose demanding requirements for the performance of crash avoidance systems. And this environment of "proximate others" is not simply physical - i.e., not simply comprised of vehicles and other objects which are inanimate "targets" for sensory detection (that is, the upper quadrant) - but is also comprised of people-based phenomenology. The lower right quadrant constitutes the locus of traffic as a sociological reality. We all know that there is a common wisdom, if you will, in driving - human if not legal rules of the road which are embedded more or less subconsciously in the minds of virtually all experienced drivers but which have been absent from the explicit knowledge base of automotive technology. It is especially in the squishy, wetware-determined, and external context of an individual vehicle's operating state that research participation by NHTSA should be most welcome and most needed. It is primarily this right-half and also lower left portions of the plane that seem to me the natural locus for NHTSA's "help" toward commercialization of crash avoidance products in motor vehicles.

In some of the breakout sessions I heard sentiment from automotive manufacturing folks suggesting that perhaps the NHTSA program should not prod excessively into "the industry's territory". In general, these comments were directed at cases in which the technological elements - the hardware, again - was primarily at issue. Where this pertains to the upper left quadrant, the point is well taken. But it helps out mutual understanding, I think, to recognize that the space marked "natural locus of NHTSA help" has not all been the traditional territory for automotive technology. Indeed, no one at all is an expert here. The complexity resident within the locus is simply tremendous. I see broad approval of the fact that NHTSA crash avoidance research program resides overwhelmingly where it's "natural".

CLOSING COMMENTS

Dr. Shladover: I want to thank August Burgett for picking up the ball on the NHTSA side to keep this event moving and really make this a success. I think it is a very favorable development that NHTSA is actively seeking this type of input to the development of their program. This really offers the opportunity for all of us to have a more effective system.

We do want to look ahead to see what kind of future such workshops we ought consider within ITS America. We are interested in any feedback that you can offer us about what you liked, and what you did not like about this workshop, as well as when you would like to see another one and what kind of coverage you would like to see in future such workshops. I think this is one of the more important things that ITS America as an organization can do to bring together people from the public and private sector to address important issues associated with ITS, such as the issues we have been dealing with here today.

If anybody would like to offer any comments from the floor on what we ought to be looking ahead to, we would certainly welcome them, and if not, please approach any of us afterwards, Gene, myself, August, Donna. We need those inputs so that we can plan for future activities.

Mr. Farber: It seems to me that all of the important issues were discussed, and I was very pleased to see that. One thing that Bob put up on the screen that just triggered a thought is the upper right-hand quadrant of his diagram (viewgraph 6) where he has got hardware as opposed to wetware and the highway as opposed to the vehicle, and what is on that Buick that might make it easier to detect. It occurred to me that nobody in any of the sessions raised the issue of the possibility of some sort of cooperative system between vehicles, transponders or something of that sort. That would have, of course, applied to the kinds of systems that Steve and Terry are investigating. As a parting shot, I would suggest that you might consider the implications of that kind of technology. With that I will thank you all very much for your attendance. (Applause.) We are adjourned.

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APPENDIX C: SURVEY RESPONSE-S

Workshop attendees had the opportunity to provide in-depth comments regarding NHTSA performance specification for each type of collision avoidance system by responding to a written survey/data recording form. Unedited survey responses are listed below, organized by collision avoidance system.

Rear End Collision

1. Are the performance specifications on the "right track?" If not, what are the suggestions for a different approach?

   To decide about the right track, it might help to think about: where the specifications are going? These specifications appeared to be useful for Frontier to use in building a system for use later in the program. For others to use the specifications, they may have reasons for wanting to know the assumptions used in analysis studies and the rationale(s) used in choosing the levels. People building their own system may want to know tradeoffs so that they can choose their own levels of performance. To me, the specifications seem to be based on what the technology can do if people use it. How much people will use the advice is an open question.

   - I question whether the operating environment specifications are realistic.
   - I think the comment the moderator made regarding "exposure rates" is particularly relevant considering the crash data drawn from FARS and GES databases. The limitations of these two databases should be stated. A second concern I have is how the performance specifications will fit within an ITS architecture that encompasses the roadway as well as the vehicle. FHWA, for example, has an ITS planning Process which would seek to achieve all sorts of goals, of which one is reduced motor vehicle crashes. At some point before deployment of vehicle-related ITS applications there needs to be a check that ensures the vehicle-related performance specifications are compatible with roadway-related ITS applications. In brief, these performance specifications should be developed within the framework of an overall ITS/ transportation planning process.
   - Too much emphasis on simulation to determine things like required range. I find the graphs that are presented counter-intuitive at times and hard to believe. You need to look at other ways of developing these graphs - other simulations or experiments. One must be very careful about requiring such things as "zero miss rates" unless trying to prevent the development of the technology. Keep in mind that a zero miss rate cannot be achieved. There does not seem to be any consideration as to what is achievable. The performance specifications should try to wind up with a system that could possibly be built.

   Specifications in certain cases must be prefaced by assumptions/conditions under which they were calculated (e.g., minim cautionary warning times, driver reaction times, etc.). Also, the specifications must raise all the relevant

performance criteria with the rationale, implications of sensor/system independent analyses. Numbers as given in the specifications are not bad, but serve as a good example for arriving at them.
Yes, they are on track. They are preliminary and only estimates, but they are based on reasonable assumptions; this is the way to begin.
How much safer should a rear-end CAS make driving to satisfy legal considerations? (Rear-end CAS should have effectiveness of xxx to reduce litigation to a xxx level).
System operation should not be limited at the lower end to 10 mph. If a system operates to o mph, it offers more benefit to the driver.

2. What experiences or lessons learned can be offered for incorporation into the NHTSA work?

Experience with trying to compare Advanced Cruise Control (ACC) with normal driving gives me reason to question some of our basic assumptions that underlie simulator work and system design. Specifically, it could be that following another vehicle is hard and unpleasant for people to do. Drivers may try not to follow other vehicles. They instead may try to pass, change lange, or drop back rather than follow another vehicle. Perhaps the NHTSA work will investigate (measure) what drivers actually do, and then use that information and understanding to re-examine earlier approaches and work.
For specifications to be useful, they must be stated in the form of effectiveness versus performance trade-offs; not absolute numbers. Instead of saying things like “all licensable vehicles” suggest specific vehicles.
Requiring performance specifications that have to be quantified is very system specific (i.e., sensor, vehicle, etc.) A clear statement of goals that define the minimum requirements (size of target, range of speeds, range of road conditions) for which rear-end collision avoidance systems are designed.
- The work is not yet far enough along to be in the “lessons learned” stage.
- Top-down, not bottom-up

Warning systems should be adjustable to local conditions and to the driver’s own experience.
Detroit manufacturers should be included with Rear-end CAS projects now to achieve future designer input. Programs should be initiated to integrate rear-end CAS with other CAS types.
Need to evaluate if Adaptive Cruise Control should respond to stationary objects.

3. Will the eventual results from the NHTSA work be useful to system designers? If not, what would be useful?

The results will be useful to system designers, but they will they need to look beyond the specifications to see what is important and to learn how performance can be improved.

Do not overspecify. Do not go beyond functional requirements.

My initial question is "who are the users, or clients, of this research?" Evidently, we are targeting automobile manufacturers (and associated contractors). However, if my comment has any relevance, then these specifications should also be of interest to those that would be involved in future transportation planning, of which ITS is a component. Within ITS, persons that are evaluating various strategies could use performance specifications as a way of understanding the benefits of one particular category of ITS measures, namely collision avoidance systems. Thus, my basic statement is this: Does NHTSA view transportation system designers (not just vehicle system designers) as possible beneficiaries of this research?"

Push more towards performance specifications. You do not need to have specifications for things like power. Assume that manufacturers and designers have some sense.

- If the results clearly indicate the required information, levels of accuracy, and repeatability, they would definitely be useful to system designers.

  Yes, these should be quite valuable to system designers. The initial specifications are preliminary, as stated, and are a first attempt at estimating the performances sought. These have been stated as specific as they can be at this stage.
- Must define and agree upon a definition of effectiveness. Should use better metrics based on statistical levels of confidence.

  Current NHTSA CAS programs produce a designer baseline. The latter will be modified to the extent different image processing and signal processing algorithms are utilized. Modifications will also occur for different vehicle types (e.g., truck versus passenger car). Also, single CAS specifications may need to be modified when multiple CAS are integrated.

  The curve of system effectiveness vs. detection range; outstanding graphic to assist system designers.

4. What guidance can be provided on methodologies to estimate the benefits which would accrue to systems designed to meet the performance specifications?

- Who benefits? Define effectiveness depending upon situation. Compare what the new situation will be compared to the current situation.
- It could be appropriate to attempt to quantify the benefits of an already existing technology using the "new" methods for determining benefits. For example, make believe it's 1985 and attempt to use the new methods to quantify the benefits of antilock brakes. Then the actual benefits of ABS, as measured by, say the Insurance Institute of Highway Safety in 1995 could be compared to the predicted benefits of ABS derived from the "new" method.
- Defining fidelity rates required on sensors. Scope for range of targets. Evaluations on a consistent basis. Scope of operating conditions (speed, accelerations) and ambient conditions (road, weather conditions).

  This is extremely difficult to address before any of the systems accrue extensive experience. My only recommendation would be to use tried-and-true

procedures and terms as far as possible.
Each CAS needs a bench mark with known safety (i.e., crash prevention) properties. In the case of run-off-road project, rumble strips were the bench mark.
Need to evaluate at least 2 categories of vehicles: a) typical car (i.e., Taurus), and b) a full size van with load. Performance recommendations regarding parameters for each extreme needs to be provided.

5. Other comments?

These comments pertain to all three of the crash avoidance subjects. They are generalizations that occurred to me. (1) the crash types are based on physical ideas rather than a perspective based on driver errors. (2) "Effectiveness" means technology effectiveness in these studies. (3) The approach seems to give no consideration to effectiveness. If the countermeasure changes the world, can you still use the data pertaining to the way the world used to be? Perhaps the goal should be to understand what is going on - what are the fundamental ideas. (4) It is very hard to get beyond what can be deduced by a quick look at accident data and informed judgement. Earlier studies support many of the same ideas. (5) Is there is a chance that a very structured approach such as that used in these studies will overlook, or miss bright ideas? (6) Can warning give the driver feedback on performance such that performance will be improved when a very risky situation develops. (7) I believe that crashes happen when the driver's expectations are wrong. Where do driver's expectations come into this? (8) Are simulators the primary way to obtain interface specifications? (9) What determines how demanding the specifications are? Do we know what a good driving situation is? Can we consider trying to improve the driving situation? Perhaps this would lead to a simpler approach. (10) How is VME or DASCAR data worked into analysis and simulation for CAS technology evaluations? Isn't there a lot of work needed to establish ways of characterizing traffic and driving behavior? (11) Aren't we putting too much emphasis on lane change or merge given the small number of crashes involved?
We need to decide the function of these specifications. Are they recommendations to designers or minimum NHTSA requirements, or what?

- The work (associated with all three systems) is definitely useful regardless of some deficiencies. It serves to create awareness to the problems and available technology, create impetus for development of new technology, and provide a set of baseline criteria/numbers future research in this are can better focus. Even partial deployment after cleaning out the bugs will result in an improved system.
- Much of what NHTSA is doing in the specifications programs was already achieved a few years ago by the French and Germans. Is NHTSA actively tracking these programs?

All parameters and measurements need to be "recommended proactive," not hard specifications to be followed.

Lane Change and Merge

1. Are the performance specifications on the "right track?" If not, what are the suggestions for a different approach?

- Perhaps these specifications are aimed at driver errors such as "inattention", wrong expectations", and "looked but did not see." Perhaps effectiveness measures should relate to these driver-related matters.
- Much regarding component performance capabilities that driver system performance specifications. Need more of a human factors component in developing performance specifications. These are not specifications yet.
  I think that these are more on track than was the Rear-end collision work. These are not so totally based on simulation; the experimental work clearly has strongly influenced the preliminary specifications which are very good.
  Noting the percentage of crashes in this category seems like this would be less effective as a CAS unless automatic control is introduced. Could be viewed more as a research platform for creating scenarios requiring lane changes and merges and studying the effectiveness of these systems. A human factors module can be included in this to broaden the scope of use of this system.
  I am concerned that this specification is losing its broad applicability by leaving out back-up sensing. It also has the potential of becoming a specification that defines a specific sensor that TRW is making. This would not serve the industry well at all.
- Once the method of warning is defined, will this have an effect on nuisance or false alarm rates? What rates are acceptable to drivers?
  Need to concentrate on proximity and drifting area.
  As a suggestion, the Daimler-Benz prototype vehicle VITA II use 2-3 element stereo cameras on both sides of the vehicle. Also used on the front bumpers a stereo camera to accommodate vehicles that quickly swerve in front. Perhaps this approach should be investigated.

2. What experiences or lessons learned can be offered for incorporation into the NHTSA work?

Commercial aviation (TCAS?) built systems tested in simulators. Took a very long time to develop.
Need more human factors information.
Human factors study on reduced mirror use with audio associated with turn signal.

- NHTSA specifications CAS programs should be coupled to the end user (Le., Detroit) now to provide useful feedback. Again, how well must lane-change CAS function to avoid litigation. The European Prometheus program has resulted in French and German prototypes which already have achieved levels of performance beyond U.S. results. Can any of this work be used in U.S. projects to avoid Ye-inventing" the wheel?

3. Will the eventual results from the NHTSA work be useful to system designers? If not, what would be useful?

   Yes, but the ideas generated will be more useful than the preliminary specifications. The designers might want to show the reasons, rationale, and evidence supporting functional goals. This might give them insight into the technology that they would choose to build **into** the system.

   - Need to provide more details as to how the recommended specifications were derived. Much of the value of this work is in the details as compared to absolute specification numbers.
   - It is not clear whether this work incorporates a human factors module. With the emphasis only on detection, system designers need a baseline requirements specification for adjoining lane, forward/rear vehicle detection systems.

   The results will not be useful if the specifications only define the sensor system TRW is developing.

4. What guidance can be provided on methodologies to estimate the benefits which would accrue to systems designed to meet the performance specifications?

   At this point in the meeting, it looks like there is something circular going on. The performance specifications are based on some sort of effectiveness measure. This measure supposedly tells what amount of a good thing is going to be achieved. So the benefit should be readily forthcoming given that the effectiveness is achieved and one knows what the good thing is worth. Question 4 seems to imply that there i more to this than simply designing to the specifications. Perhaps the point is that designing to specifications does not necessarily means that a good (beneficial) system will be developed. TRW's planned testbed sounds like a useful tool for studying effectiveness.

5. Other comments?

   I would point out that if one has a lane change warning system AND a lane keeping system, it will warn when crossing the lane strips (lane keeping) unless one signals a lane change by using the turn signal. This would encourage use of turn signals.

Run-Off-Road

1. Are the performance specifications on the "right track?" If not, what are the suggestions for a different approach?

For all three Collision Avoidance Systems, are the specifications too dependent upon technological capability. Perhaps how drivers will interpret warnings should be key in determining effectiveness, and information on effectiveness versus level of system capability would be more useful to others than one set of specifications.

- Need specifications to accommodate variations in different classes of vehicles.
- Include specifications addressing infrastructure quality.
- Even though infrastructure deployment is expensive and extensive, how do they compare to cost of buying a single vehicle roadway departure warning system, and time until implementation and liability?
- I think we are mixing up the terms "functional goals" and "specifications". Functional goals are equivalent to problem statements (e.g., determine if vehicle is on roadway). Specifications are how you satisfy functional goals (e.g., disengage system at speeds below 15 mph). Functional goals are not hardware dependent. Specifications tend to be very hardware oriented, but can be generalized at times (e.g., measuring lateral position to 0.1 ft.).
- Performance specifications should be based on performance of system, not components.
- Further work is needed to address how well a collision avoidance system must perform to avoid litigation, and how run-off-road CAS can be integrated with other CAS types.

2. What experiences or lessons learned can be offered for incorporation into the NHTSA work?

Talk to the end user.

- I think "public acceptance" must be combined with "public education" to prepare the public for system limitations and to educate the public that run-off-road incidences happen in benign circumstances.
- Issues associated with marketability, cost, liability, repair cost, false alarm tolerance, driver control over system (on/off), compliance to warnings, etc.
- Road departure is a function of road conditions (i.e., friction), tire condition and inflation pressure, and roadway geometry and vehicle speed. We must track all conditions.

Currently none of the "big three" in Detroit are involved with run-off-road, rear-end, or lane-change countermeasure programs. Unless Detroit becomes involved, where do the above NHTSA programs go? In Europe, the automobile manufacturers are directly involved in such programs.

3. Will the eventual results from the NHTSA work be useful to system designers? If not, what would be useful?

The specifications need to indicate why a particular reason for setting the specifications (what goal does the spec pertain to? how are measurements made to check whether the specs are met?).

- When systems are deployed, support from NHTSA is needed to inform the public of the safety utility aspects of these systems.

The resulting specifications should be sensor and control hardware independent.

- Results will be useful to the extent that future designs mirror the original run-off-road CAS embodiment. The specifications, for example, may change if a future designer uses run-off-road CAS algorithms other than ones used on current run-off-road projects. Some specifications are more robust and less algorithm dependent such as the time it takes to maneuver a particular vehicle back to normal lane keeping after it has deviated a certain amount.

4. What guidance can be provided on methodologies to estimate the benefits which would accrue to systems designed to meet the performance specifications?

Get DASCAR operational soon enough to use for this.

It is very important to communicate the results to consumers. Therefore we must convert all technical results into understandable language that helps consumers (or regulators) make decisions or advocate the availability of systems.

How good must the benefits be so that the NHTSA CAS budget is not cut by Congress?

5. Other comments?

Should the "specifications" include a black box reader for accident reconstruction?

- How are all these collision avoidance systems going to be integrated with one another? Try specifications for that?
- How do you define a "near miss"? One persons "near miss" is another's successful lane change.

My three main points are: (1) Detroit needs to be directly involved in the NHTSA specifications development projects, (2) Future CAS systems need to be integrated (consumers will not buy a system that addresses only one crash type), and (3) How well must a CAS perform to avoid litigation?Can this be quantified?

General: Collision Avoidance Systems

1. Are the performance specifications on the “right track?” If not, what are the suggestions for a different approach?

   These are not performance specifications, they are design specifications. What industry needs is a test that will prove that our system does meet the goal. Once the systems are operating in place, the challenge will be to process the data to understand driving and crash avoidance. There is a need to develop methods for penetrating the data and then expressing the results as logically as possible. This is follow-on work that will feedback to future versions of DASCAR and perhaps VME.

2. What experiences or lessons learned can be offered for incorporation into the NHTSA work?

   In the SAE, when we write a performance specification, we start with the test.

3. Will the eventual results from the NHTSA work be useful to system designers? If not, what would be useful?

   No. Tests to test our systems is what are needed. Industry can handle the technology, NHTSA can help with institutional or human factors type issues.

4. What guidance can be provided on methodologies to estimate the benefits which would accrue to systems designed to meet the performance specifications?

   No comments were received

5. Other comments?

   Regarding driver training for the use of these technologies. There may exist opportunities to use groups that are already involved with regular driver training. For example, the American Automobile Association (AAA) offers driver training to select groups (e.g., senior citizens). State agencies are another resource. Finally, commercial driving schools are an alternative. Ideally, potential technologies would be introduced by those entities as part of their regular driver training curriculum. These entities may also have input for how newer technologies can be introduced such that students (drivers) learn how to use them effectively.
   Perhaps system throughput would be reduced as a result of increased vehicle headways that would occur should drivers heed a Collision Avoidance System (CAS). This may be possible, but the appropriate equations assume a certain

flow distribution. Capacity should not be affected on multi-lane uncongested roads operating well below capacity. On roads operating at capacity, keep in mind that delays are often incurred by incidents - even a disabled vehicle on the shoulder can disrupt traffic flow under congested conditions. In this scenario, the capacity inducing benefits associated with increased headways may very well outweigh the disbenefits of slightly reduced throughput.

- More emphasis needs to be placed on practical, real world driving situations. We need to immediately equip large fleets. Prototype systems should be installed now and so we can start recording feedback. I suggest installing systems on fleets that involve high mileage (Professional drivers, such as Federal Express, UPS, taxi cabs, etc.) We can only simulate a certain percentage of situations. Predicting false alarm rates only works in text books. Real world experience will tell us more.

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